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CRITIQUE OF ACID LAKES AND FISH POPULATION STATUS IN THE ADIRONDACK REGION OF NEW YORK STATE

by

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In the United States, the debate concerning the relationship between acidic deposition and acidification, and acidification and fish population responses, has focused on the Adirondack region of New York State. The objectives of this study have been to summarize and critique all available data on Adirondack lakes. Using this existing data base, questions regarding the acidity status of Adirondack lakes and potential effects of acidification on fish are addressed. However, due to uncertainties associated with the data base, discussion and analysis are presented with authors' qualifications.

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ABSTRACT

In the United States, the debate concerning the relationship between acidic deposition and acidification, and acidification and fish population responses, has focused on the Adirondack region of New York State. Only for the Adirondack region has extensive loss of fish populations as a result of acidic deposition been reported. Our objectives have been to summarize and critique all available data on Adirondack lakes. Based on this existing data base, we have addressed a series of key policy questions regarding the acidity status of Adirondack lakes and potential effects of acidification on fish. Our answers, however, must be qualified due to uncertainties associated with the existing data.

693 lakes have laboratory electrometric, air-equilibrated pH measurements within the last 10 years (1974-1983), excluding 1979 data. Of these, 171 (24.7%) had mean summer surface pH values below 5.0. Adjusting the sample for potential biases related to lake area and/or elevation, an estimated 17 to 28% (95% confidence interval; mean 22%) of the 2759 lakes in the Adirondack Ecological Zone are acidic ($pH < 5.0$). The sample of 693 lakes may, however, be biased in ways unassociated with area and elevation. We can neither identify nor correct for these biases, if they exist, with the available data.

Changes in pH over time (based on linear regression analyses) for the region as a whole have not been significant ($p > 0.05$). High elevation (> 610 m) lakes and lakes with current $pH < 5.0$ appear, however, as a group to have experienced a significant ($p \leq 0.05$) decrease in pH over time. Potential effects due to changes in measurement methods for pH were not, however, considered. Causes for acidification or acidic conditions were not explicitly evaluated.

Changes in fish communities over time, and explanations for observed changes (including shifts in stocking policy, other fisheries management, and habitat alteration) were evaluated without reference to lake identity or water chemistry data. Ratings of fish community status were significantly ($p \leq 0.05$) correlated with lake pH. This correlation, while not proving cause-and-effect, adds credence to the argument that fisheries declines have occurred in the Adirondacks as a result of acidification. For lakes with adequate data for evaluation of fish community status, the numbers of fish communities judged adversely affected (loss of one or more populations) apparently by acidification (i.e., no obvious alternative explanations) ranges from 50 to 200-250, depending upon the definition of 'adequate evidence' for detection of effects. For Adirondack lakes in general, 400-500 lakes (14-18%) may have been adversely affected. These are, however, fairly rough estimates and associated levels of uncertainty cannot be quantified.

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I. INTRODUCTION

In the United States, the debate concerning the relationship between acidic deposition and acidification of surface waters, and acidification and fish population responses has focused on the Adirondack region of New York State. The Adirondack region is one of the largest sensitive (low alkalinity) lake districts in the eastern U.S. (Galloway and Cowling 1978, Omernik and Powers 1982), and also receives large annual inputs of acidic deposition (in 1980, 40 kg SO_4^{2-} ha^{-1} yr^{-1}, average precipitation pH of 4.1, Gibson and Linthurst 1982). Only for the Adirondack region has extensive loss of fish populations as a result of acidic deposition been reported (Pfeiffer and Festa 1980, Schofield 1982, Baker 1984), and discussion of the Adirondack data base plays an important role in all major comprehensive assessments on acidic deposition prepared to date (National Academy of Sciences 1981, International Electric Exchange 1981, U.S./Canada Memorandum of Intent 1983, Altschuller and Linthurst 1984).

Unfortunately, the Adirondack data set and available analyses leave much to be desired. As a result, the notion that Adirondack lakes and streams and fish populations have been severely impacted by acidic deposition is still controversial. Our objectives, therefore, have been to summarize and critique all available Adirondack data, and to provide a written report suitable for public review and for inclusion within the 1985 Assessment of Current Damages as part of the National Acid Precipitation Assessment Program (NAPAP). Our analyses compliment on-going activities within the National Surface Water Survey (NAPAP project E1-23). Comparison of our results, based upon existing data bases, with those from the National Survey will provide some indication of the utility of existing data, despite concerns regarding data quality and selection of representative samples.

Our interests focus on effects of acidification on fish populations in the Adirondacks. Evaluations of effects on fish, however, require some consideration of the current acidity status of surface waters and evidence for changes in water chemistry through time. We have, therefore, also included some analysis of water chemistry data, but recognize that this analysis is not exhaustive. A more detailed assessment of chemical conditions in Adirondack lakes for the 1985 NAPAP Assessment of Current Damages will be provided by other investigators (e.g, NAPAP projects E2-01.2 and E2-11). The remainder of this section provides brief summaries of (1) the quantity and types of water quality and fisheries data available for analysis, (2) literature on water chemistry and acidification of Adirondack surface waters, and (3) literature on the role of acidification in the decline and loss of fish populations in the Adirondacks.

1. QUANTITY OF DATA AVAILABLE ON WATER QUALITY AND FISH POPULATION STATUS IN THE ADIRONDACK REGION OF NEW YORK STATE.

For the purposes of this report the term Adirondack region refers to the Adirondack Ecological Zone as defined by Pfeiffer (1979). The

Adirondack Ecological Zone encompasses over six-million acres in northeastern New York State (Figure 1) outlined by the 1000 foot (305 m) land elevation contour, with some modification. The Adirondack Ecological Zone is slightly larger in area than the Adirondack State Park, but excludes low elevation areas on the eastern perimeter of the Park that are not considered representative of the Adirondack Mountains. A more detailed description of the boundaries of the Adirondack Ecological Zone is provided in Pfeiffer (1979).

The New York State Department of Environment Conservation (DEC) reports that the Adirondack Ecological Zone encompasses approximately 2759 lakes and ponds (99,700 surface ha) (Colquhoun et al. 1984) and an estimated 9340 km (6800 ha) of significant fishing streams (Colquhoun et al. 1981). Twenty-two fish species are native to the region including brook trout (Salveninus fontinalis), lake trout (Salvelinus namaycush), brown bullhead (Ictalurus nebulosus), white sucker (Catostomus commersoni), creek chub (Semotilus atromaculatus), lake chub (Couesius plumbeus), and common shiner (Notropis cornutus) (Greeley and Bishop 1932). In addition, a variety of other species (e.g., smallmouth bass, Micropterus dolomieui; yellow perch, Perca flavescens) have been introduced into Adirondack waters, especially into the larger, more accessible lakes. Brook trout are frequently the only game fish species resident in the many small headwater ponds that are located at high elevations and are particularly susceptible to acidification (Pfeiffer and Festa 1980). Although native to the Adirondacks, in some waters brook trout populations were introduced and must be maintained by stocking due to a lack of suitable spawning area.

Information relevant to effects of acidification on Adirondack fish populations evolves primarily from three sources: (1) a comprehensive survey of water quality and fish populations in many Adirondack surface waters conducted by the New York State Conservation Department in the 1920's and 1930's (New York State Conservation Department 1929, 1930, 1931, 1932, 1933, and 1934), followed by sporadic sampling of lakes and streams up until the 1970's (data maintained on file by the State), (2) in 1975, a complete survey of all lakes (214) located above an elevation of 2000 ft (610 m) (Schofield 1976a), and (3) from 1979 to the present, accelerated sampling by the DEC of lakes considered particularly sensitive to acidic deposition. All water quality and fish survey data available (both historic and current) from these sources have been compiled into a computerized data base termed FIN (Fish Information Network) at North Carolina State University. In addition, FIN contains unpublished water chemistry and fish survey data collected by Carl Schofield (Department of Natural Resources, Cornell University, Ithaca, NY), including fisheries data collected as part of RILWAS (Regional Integrated Lake Watershed Acidification Study) and water quality on 50 lakes sampled by Charles (1982). All data analyses conducted for this report are based on the FIN data base. Further details on FIN and the quantity and type of data included in the data base are provided in the final report for NAPAP project E3-24 (Baker et al. 1984).

Two projects, the National Surface Water Survey (NSWS) and the Adirondack Lake Survey Corporation (organized by the DEC, funded by the Empire State Electric Energy Research Corporation) (ALSC) will provide

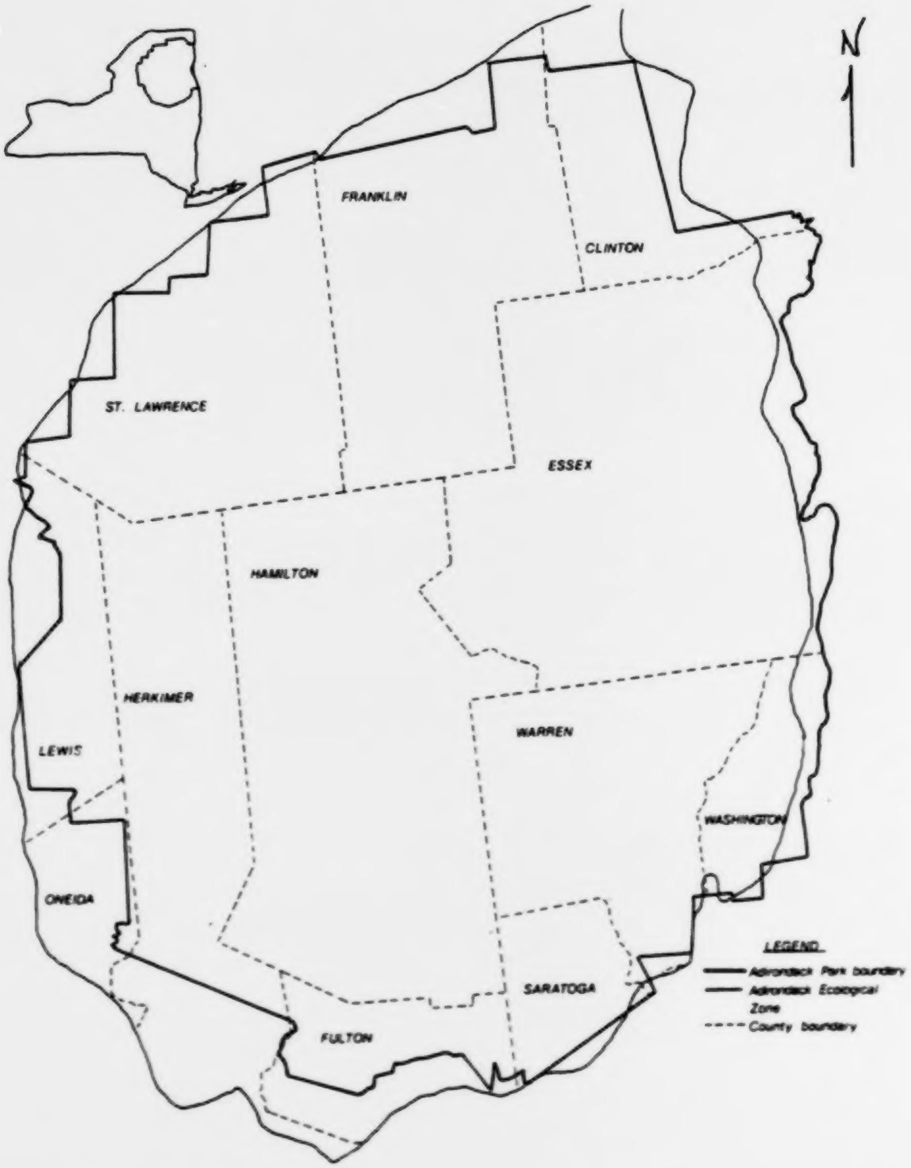
N
FRANKLIN
CLINTON
ST. LAWRENCE
ESSEX
HAMILTON
HERKIMER
LEWIS
WARREN
WASHINGTON
ONEIDA
SARATOGA
FULTON
LEGEND
Adirondack Park boundary
Adirondack Ecological Zone
County boundary

Figure 1. Map of the Adirondack Park and the Adirondack Ecological Zone (Source: Colquhoun et al. 1984). For purposes of this report, the Adirondack region is defined as the Adirondack Ecological Zone.

significant quantities of new data (on water chemistry and fish populations) in the near future. Results from the first phases of these studies were released in 1985. These results can be compared to analyses based on FIN, but unfortunately a complete, combined analysis is not possible at this time.

The existing data base on water quality and fish population status for the Adirondack region is reasonably extensive. For lakes, current (1974-1983) water quality data are available for 24.8% of the total resource (48.1% on the basis of surface area), and fish survey data for 52.3% (91.2% on the basis on surface area) (Table 1).

Table 1. Availability of Data on Water Chemistry and Fish Populations for Lakes and Ponds in the Adirondack Region of New York

	Adirondack Ecological Zone		FIN data base	
Type of Information	Number of Lakes	Total Area (ha)	Number of Lakes	Total Area (ha)
TOTAL	2759	99,666	3403	106,929
Chemical Data Available	1543	95,304	1647	99,864
Current* Chemical Data Available	693	47,982	705	49,981
Estimate of Δ pH with Time	650	58,903	673	66,034
Fish Survey Data Available	1461	90,897	1610	96,712
Current* Fish Survey Data Available	427	57,495	450	61,117

*Current data refers to data collected within the last 10 years, 1974-1983. Current chemical data refers to electrometric, air-equilibrated laboratory summer surface measurements of pH, excluding 1979 data from the DEC.

Information on streams is much less complete. Colquhoun et al. (1981, 1982, 1984) presented water quality data for about 226 streams, and fish population data for 36 streams. Because of the paucity of fisheries data for Adirondack streams, the remainder of this report focuses on lakes, ponds, and reservoirs in the Adirondacks.

Despite the magnitude of the data base, the Adirondack data set still leaves much to be desired. Two major issues are: (1) representativeness of the lakes sampled and (2) data quality. Surveys of Adirondack resources have certainly not been random. A large proportion of the existing data were obtained by the Bureau of Fisheries within the DEC. Often these surveys concentrated on readily accessible waters with productive fisheries or with particular fisheries management problems. In recent years, the DEC has recognized the need for more information on waters potentially impacted by acidic deposition, and surveys have been biased toward lakes most likely to be sensitive or already impacted. Since the total Adirondack data base combines many different surveys for many different purposes, the nature of the biases in the full data base is not clear. It is obvious, however, that use of existing data as a basis for extrapolations regarding lakes in the Adirondack region as a whole is equivocal and that results must be interpreted with caution. In addition to concerns related to sampling design, questions arise about the quality of individual water chemistry measurements and surveys of fish populations. Sampling and analytical procedures, and data quality have varied greatly. Data analyses must account for these uncertainties.

2. LITERATURE ON THE ACIDITY STATUS AND ACIDIFICATION OF ADIRONDACK SURFACE WATERS

Although much has been written analyzing the analysis of Adirondack water quality data (e.g., Church 1984, Marcus et al. 1983), the number of publications presenting original data and analyses is actually fairly small. Since we are principally concerned with evaluating the acidity status and acidification of Adirondack surfaces waters, we have not included publications on intensive studies of one or a few systems, which focus on processes of acidification (e.g., Galloway et al. 1983, Driscoll and Schrafran 1984). This section is not intended to be a comprehensive critique of the available literature; only a brief review to set the stage for analyses within this report.

Four reports from the DEC (Colquhoun et al. 1981, 1982, and 1984, Pfeiffer and Festa 1980), and Schofield (1976b) provide results from extensive surveys of water quality in the Adirondacks useful in interpreting the extent of acidic waters in the region. Schofield (1976b) surveyed all high elevation lakes (> 610 m) in 1975 and noted that 51% had pH levels less than 5.0. High elevation lakes, however, constitute a particularly sensitive subset of Adirondack lakes, and this percentage would not apply for the entire Adirondack Region. In the most recent DEC report, which includes data from earlier DEC reports and from Schofield (1976b), Colquhoun et al. (1984) noted that of the 1,047 waters with one or more measurements of summer surface pH from 1974 to the present, for 19%

the most recent pH value was below 5.0 (Table 2); the distribution of these lakes with pH < 5.0 is illustrated in Figure 2. Thirty-nine of 202 (19.3%).

Table 2. Acidity Classification Summary for Ponded Waters in the Adirondack Ecological Zone with a Post 1974 Summer Surface pH; Taken from Colquhoun et al. (1984).

pH	Number of Lakes	%	Surface area (ha)	%
< 5	199	19.0	3,560	3.9
5-6	264	25.2	9,448	10.3
> 6	584	55.8	78,394	85.8
Total lakes sampled	1,074		91,402	
Percent of total Adirondack zone	38		92	
Total Adirondack zone resource	2,759		99,666	

streams surveyed in 1982 had spring pH minima < 5.0 (Figure 3). Since most of the very large lakes in the Adirondacks have been sampled, the average size of lakes sampled (87 ha) is somewhat greater than the average size of lakes in the Adirondack region (36 ha). The average size of the remaining 1712 lakes not yet sampled is 5 ha. Colquhoun et al. (1984) concluded that since many of these lakes not yet sampled were small and located at high elevations (factors correlated with lake acidity), it is likely that a high proportion of the remaining 1712 lakes have pH < 5.0. Of the 199 lakes classified as pH < 5.0, 20% are based on 1979 pH measurements of questionable quality (Schofield 1982). Of the total 1047 lakes sampled, 31% had pH values measured in 1979.

Evaluations of acidification trends in Adirondack surface waters fall into four categories: (1) comparisons of historic and current water chemistry, with only two measurements per lake (separated by > 30 years) but data for many lakes (Schofield 1976b, Pfeiffer and Festa 1980, Schofield 1982), (2) long-term trend analyses on single or a few sites (Schofield 1976a, Peters et al. 1982), (3) application of Henriksen's (1980) empirical model for lake acidification (Schofield 1982, Wright 1983, Colquhoun et al. 1984), and (4) paleolimnological techniques (e.g., Charles 1984, Norton 1984). Each of these procedures suggests that at least some Adirondack lakes have experienced increases in acidity over time in the last 10-100 years. Each is summarized briefly in the following paragraphs.

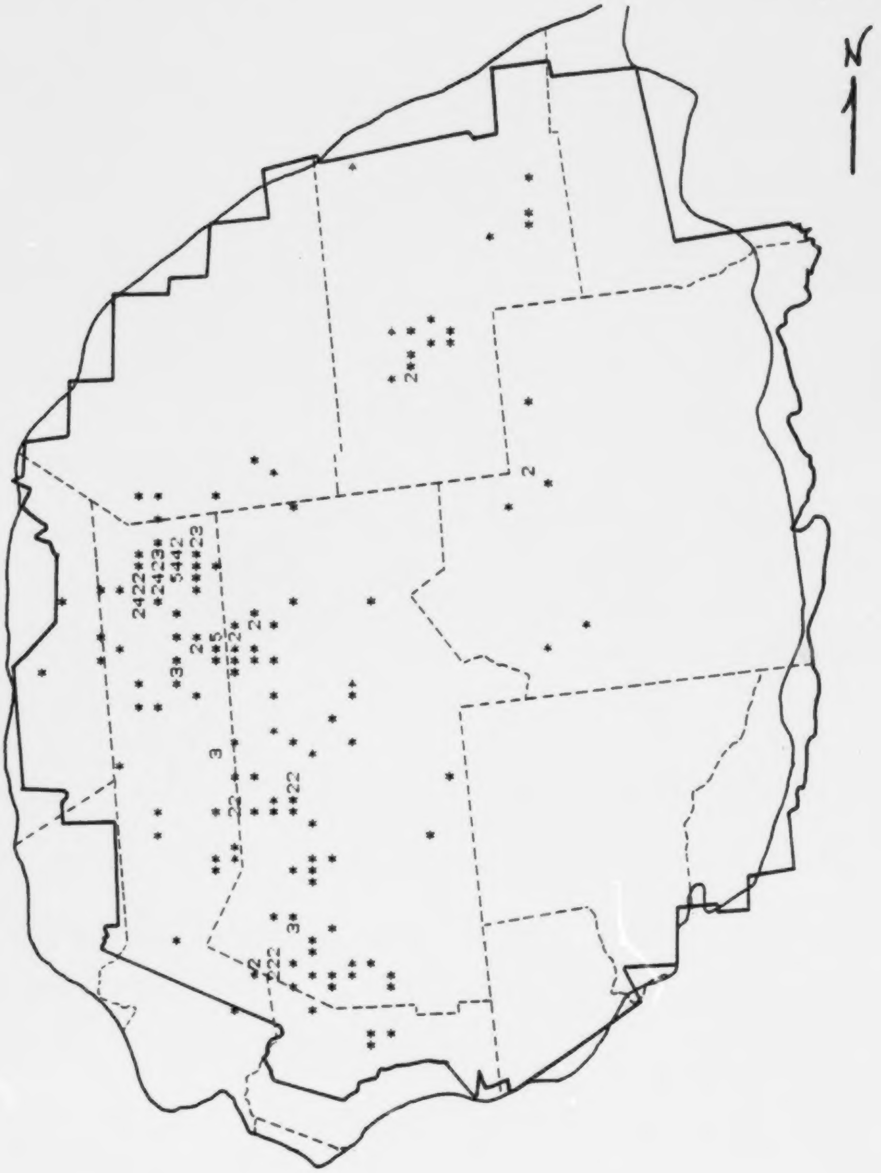

Figure 2. Location of waters in the Adirondack Ecological Zone with a post 1974 summer surface pH of less than 5.00 (n = 199), from Colquhoun et al. (1984).

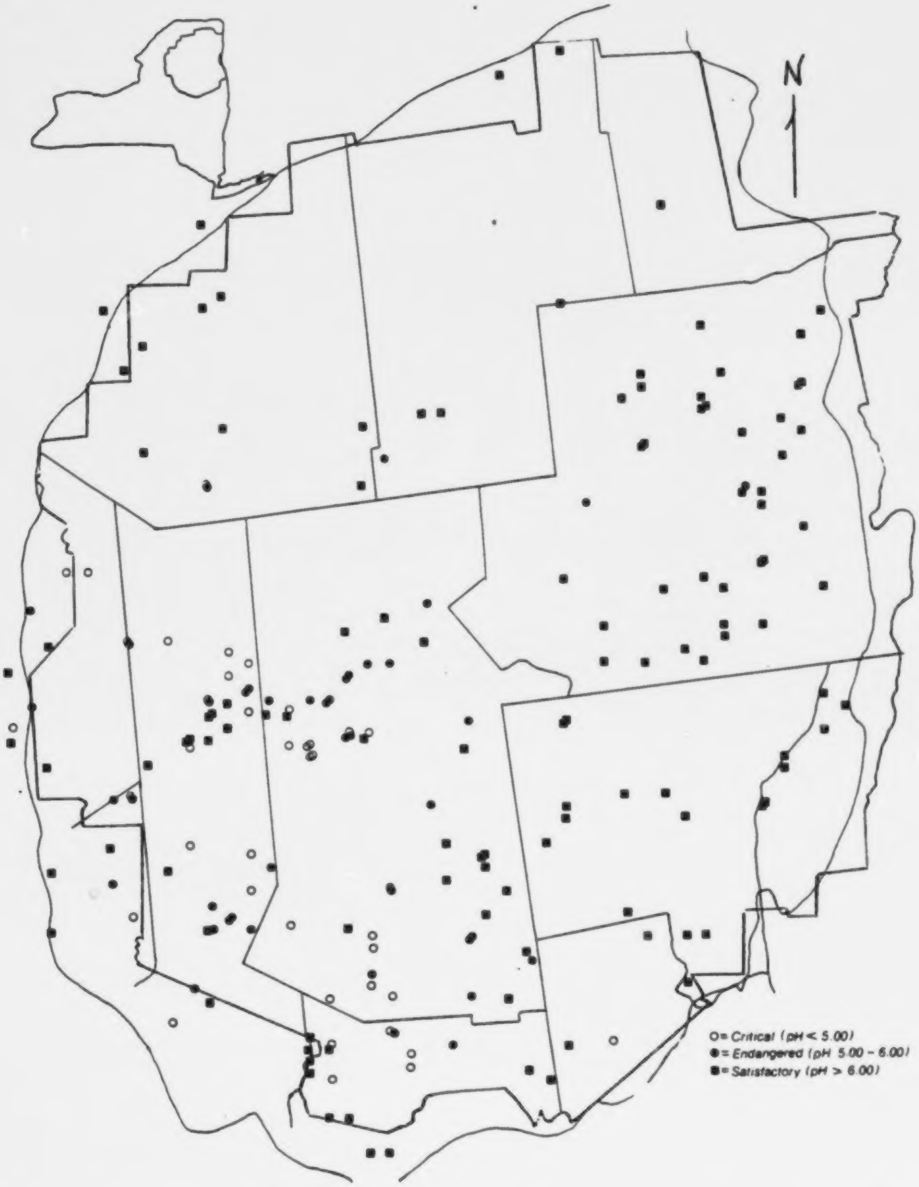
N
○= Critical (pH < 5.00)
●= Endangered (pH 5.00 - 6.00)
■= Satisfactory (pH > 6.00)

Figure 3. Location and general pH category (based on spring pH minima) for Adirondack streams sampled in 1982 (n = 202), from Colquhoun et al. (1984).

Schofield (1976b) was the first to report an apparent acidification of Adirondack waters as a result of acidic deposition. For 40 of the 214 high elevation lakes surveyed in 1975 historic colorimetric pH measurements were available from the period 1929-1937. In 1970, 19 of these 40 lakes had pH < 5.0 (Figure 4). Schofield (1976b) did not discuss the potential influence of the different methodologies for pH measurements in the two data sets. Pfeiffer and Festa (1980) expanded on this analysis, reporting historic (1930-1934) and current pH (1979) data for 138 Adirondack lakes: 59% of the lakes had a lower pH in 1979 than in the 1930's, 25% had a higher pH, and 16% had not changed (Figure 5). Colorimetric pH measurements for the 1930's were compared to 1979 measurements using the Hellige colorimetric methodology. Schofield (1982) used these same data, calculating the difference in pH as change in H^+ concentration in $\mu eq/\ell$ (Figure 6). Prior to estimating hydrogen ion change, colorimetric pH values were corrected to correspond to electrometric pH measurements. Twenty-seven (19.6%) of the lakes increased by 4 μeq H^+/ℓ or more over the 45-49 year period; 16 lakes (11.6%) increased by 10 μeq H^+/ℓ or more.

There are few lakes or streams in the Adirondacks with sufficient data (> 10 observations over 10 or more years) for analysis of long-term trends in water chemistry. Schofield (1976a) in an unpublished report to the DEC evaluated long-term changes in alkalinity and hardness for Hinckley Reservoir on West Canada Creek on the southwestern edge of the Adirondack region. The reservoir serves as a water supply for the city of Utica, and data were available from the Utica City Water Board from 1924-1975. Although data quality is uncertain and methodologies probably changed over time, the data do suggest some long-term decline in alkalinity and hardness (Figure 7). The rapid decreases in alkalinity and hardness during the 1940's and late 1960's - early 1970's correspond to wet periods, separated by a severe drought during the early 1960's, when alkalinity and hardness levels were observed to increase. Schofield (1976a) and Peters et al. (1982) have analyzed water quality data collected by the U.S. Geological Survey over an 11-year period (1965-1975) at a gauged station on the East Branch of the Sacandaga River. Both researchers concluded that a significant decrease in alkalinity had occurred over the 11-year period. Note that this sample period, 1965-1975, corresponds to the second period of rapidly decreasing alkalinity at Hinckley Reservoir. At both sites, long-term trends in pH were not apparent.

A third approach to assessing acidification in the Adirondacks applies the empirical model for lake acidification developed by Henriksen (1980) to current water chemistry or current and historic water chemistry. Since application of this model requires various assumptions about baseline conditions and the process of acidification, which we do not have space to review here, we recommend that the reader refer to the original papers for further details. Wright (1983) applied Henriksen's model to the 1975 water quality data for 206 high elevation Adirondack lakes collected by Schofield (1976a). Comparing the predicted preacidification pH distribution for these lakes to the 1975 measured pH distribution suggests major increases in acidity in most or all of these lakes (Figure 8). Colquhoun et al. (1984) applied the same model to 1982 chemistry data for 139 Adirondack streams. Model results suggested that 77 of these (55%) had been

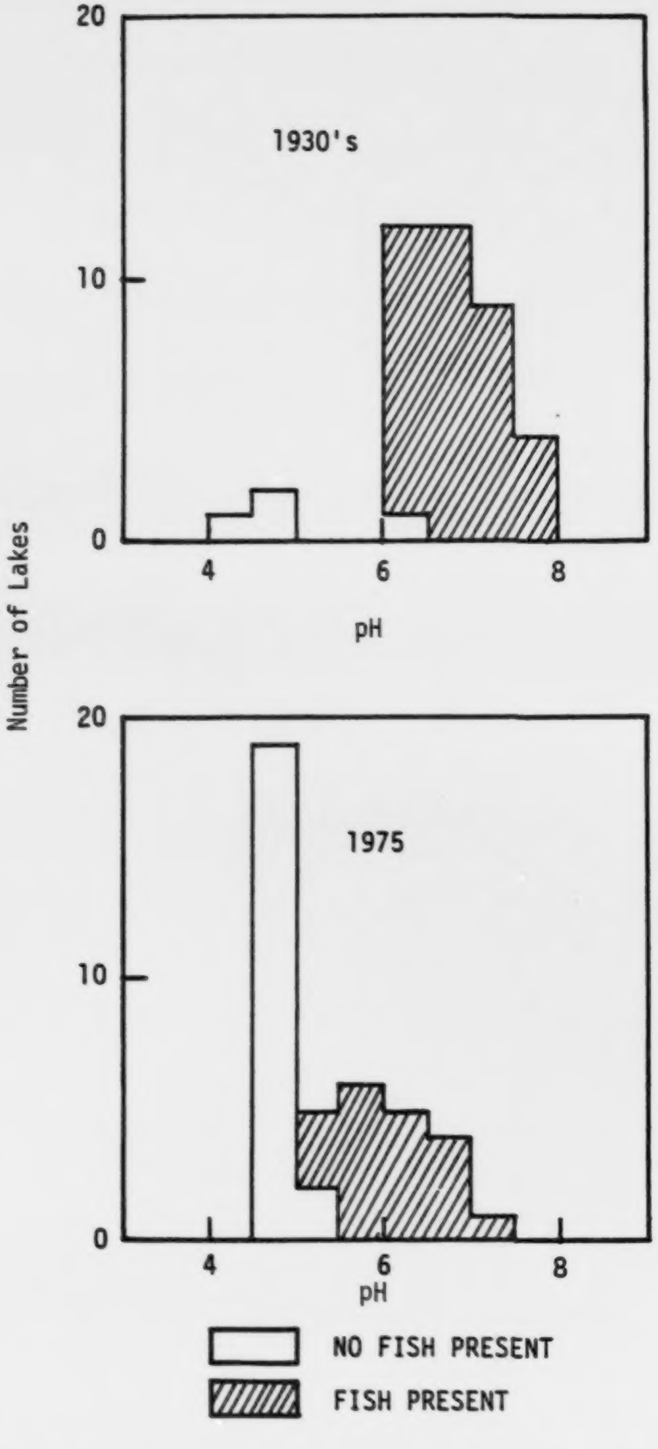

Figure 4. Frequency distribution of pH/fish population status in 40 Adirondack lakes greater than 610 m elevation, surveyed during the period 1929-37 and again in 1975. Adapted from Schofield (1976b).

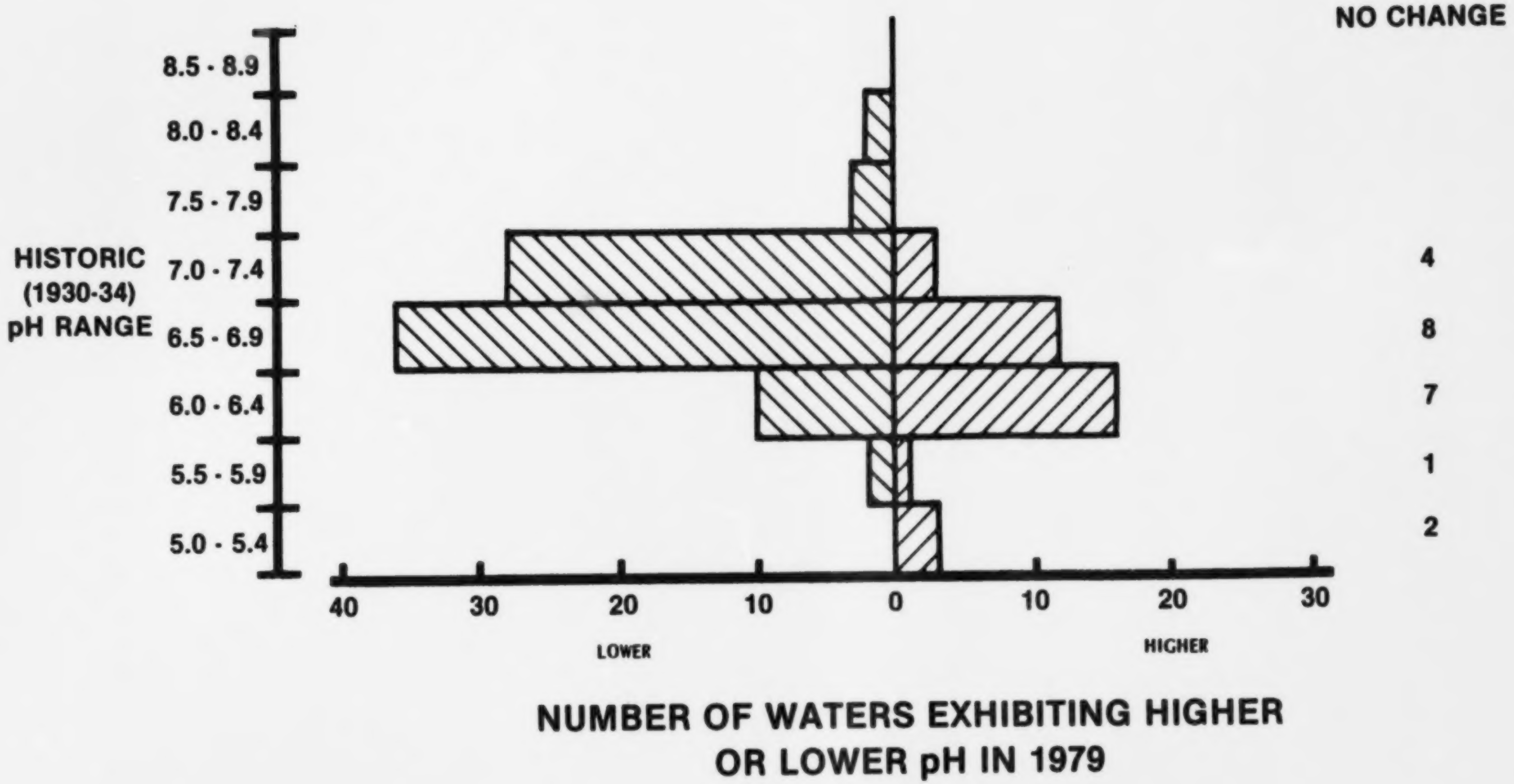

Figure 5. Comparison of historic and recent pH values (colorimetric) for a set of 138 Adirondack lakes, from Pfeiffer and Festa (1980).

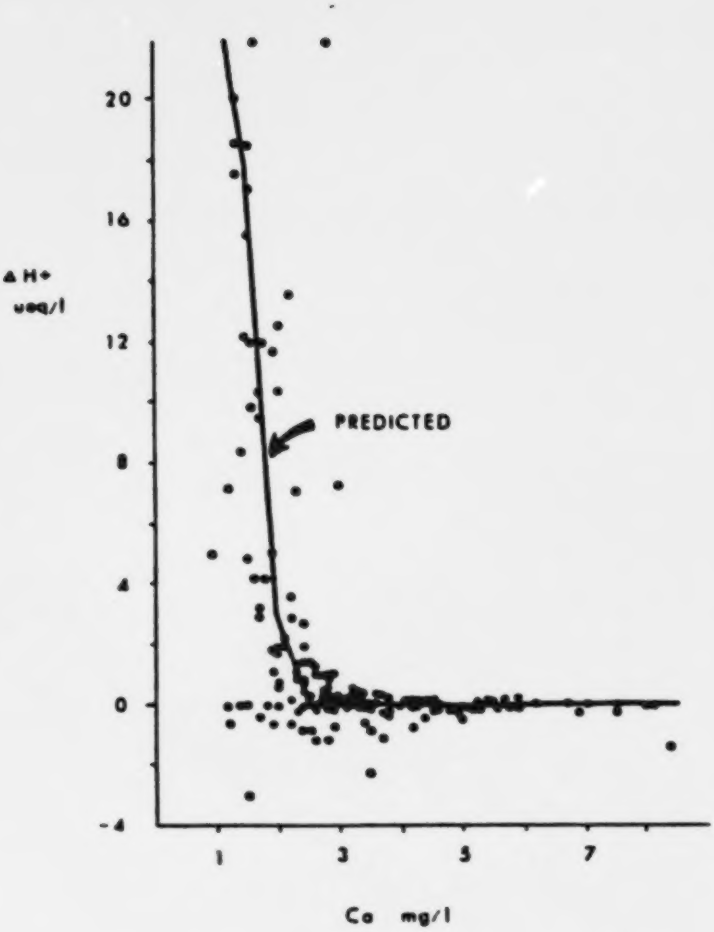

Figure 6. Change in hydrogen ion concentration of Adirondack lakes between the 1930's and 1970's, as a function of calcium levels in the latter period, from Schofield (1982).

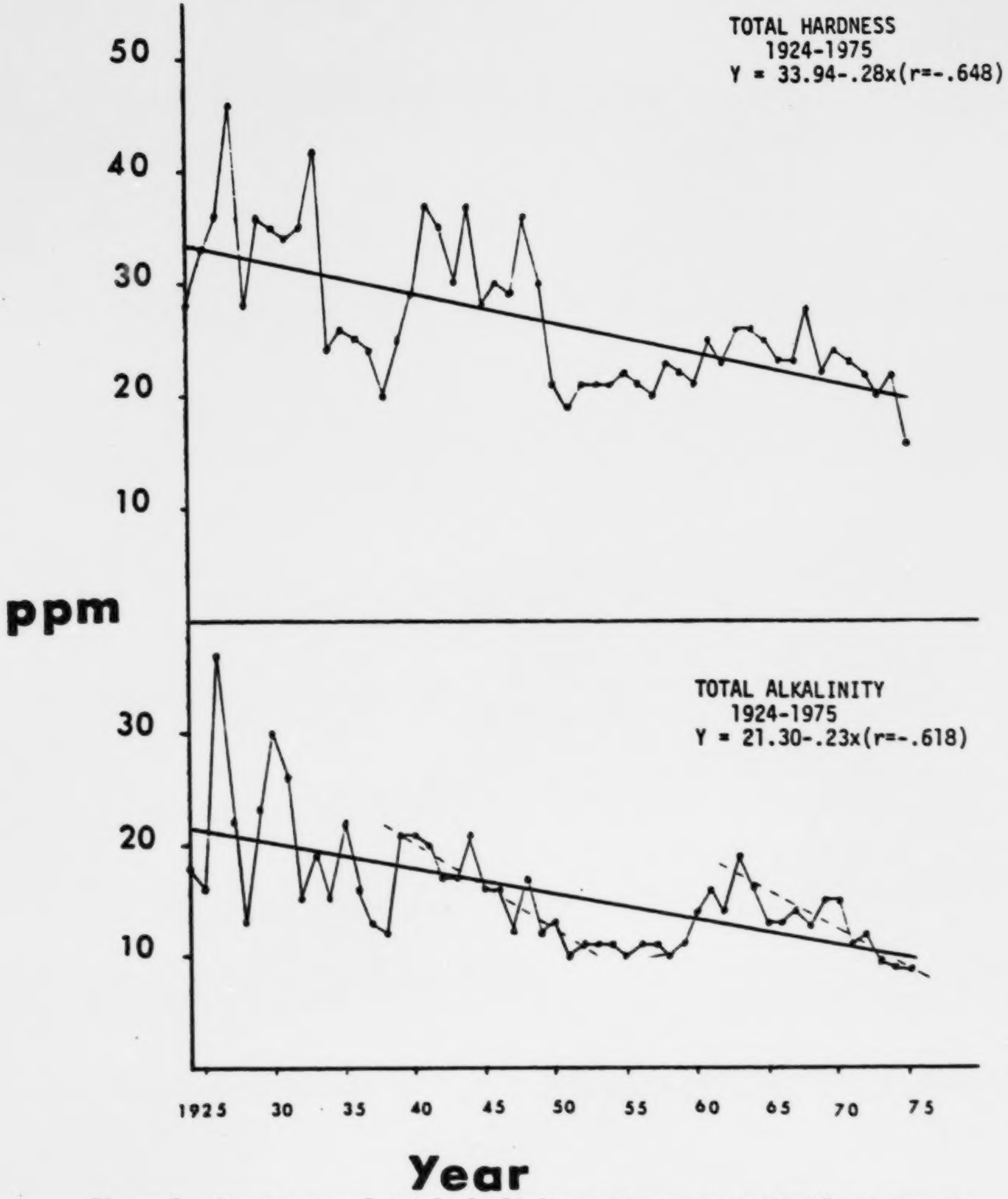

Figure 7. Average annual total alkalinity and hardness in Hinckley Reservoir, New York. (Annual means are based on daily measurements from 1924-28 and weekly samples from 1929-75.) Source: unpublished report, Schofield (1976a).

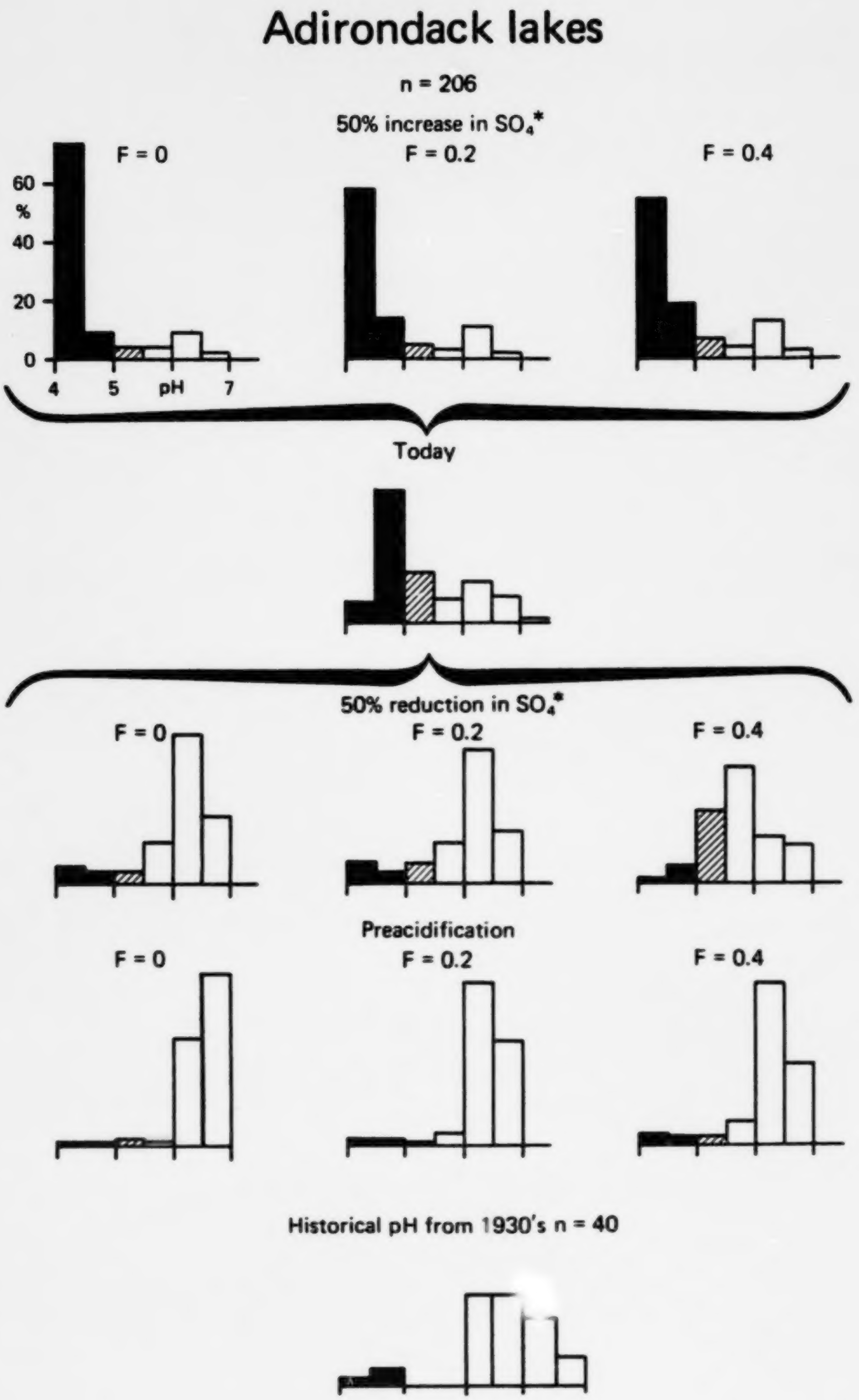

Figure 8. Measured and predicted pH frequency distributions for 206 high-elevation lakes in the Adirondacks under 4 loadings (present-day, 50 percent increase, 50 percent decrease and "preacidification") at 3 F-factors, 0, 0.2, and 0.4. Also shown is the pH frequency distribution for 40 high-elevation lakes sampled in the 1930's (from Schofield 1976). Source: Wright (1983).

acidified. Schofield (1982) compared model predictions, based on current water chemistry, to observed changes in pH over the period 1930-34 to 1979 for 138 Adirondack lakes (Figure 6). All these results (Wright 1983, Colquhoun et al. 1984, Schofield 1982) should be interpreted with caution. Henriksen's model was developed for lakes with low concentrations of dissolved carbon (DOC). Application of the model to waters with high organic acid concentrations results in over-estimation of acidification. A significant number of waters in the Adirondacks are highly colored, suggesting high levels of DOC. Waters with high DOC have not been excluded from the above analyses. For example, the FIN data base suggests that 37% of the high elevation lakes are colored light brown or brown, and thus may have high levels of DOC.

Finally, paleolimnological techniques have been used to assess acidification of Adirondack lakes. Paleolimnological studies based on diatom analyses are available for 10 lakes (Del Prete and Schofield 1981, Whitehead et al. 1981, Del Prete and Galloway 1983, Charles 1984). Although analyses were not complete for all lakes, the data do suggest that the 5 lakes with current pH < 5.0 have all experienced some acidification. Diatom analyses for lakes with current pH > 5.0 showed no indications of increasing acidity. Charles (1984) provided a detailed profile of inferred pH for Big Moose Lake, NY (Figure 9), noting that the apparent decrease in pH beginning in the mid-1950's is corroborated by historical water chemistry data and by the associated decline and loss of fish populations in the lake. Norton (1984) analyzed sediment cores from 10 Adirondack lakes for changes in chemical content and concluded that

> "Acidification of lake water is indicated for all lakes with present pH < 5 (8 of 10) by declining CaO concentrations and deposition rates (DR) in sediment for perhaps the last 100 years, declining Zn concentrations and DRs since 1950, and declining MnO concentrations and DRs."

Examination of the data, however, indicate a great deal of variability lake-to-lake and we question whether such a conclusion is justified.

Together these publications provide support for the contention that acidification of Adirondack lakes and streams has occurred within recent years (10-100), and that a significant fraction of Adirondack waters are currently acidic (pH < 5.0).

3. LITERATURE ON THE ROLE OF ACIDIFICATION IN THE DECLINE AND LOSS OF FISH POPULATIONS IN THE ADIRONDACKS

In 1976(b), Schofield published the first evidence that acidification of surface waters had resulted in the loss of fish populations in the Adirondack region. From a 1975 survey of high elevation (> 610 m) lakes in the Adirondacks, he noted that a relatively large proportion of the lakes had high levels of acidity and that these high levels of acidity were correlated with the absence of fish. The proportion of lakes with no fish (based on survey netting) increased sharply below pH 5.0. Of the lakes with pH < 5.0, 82% had no fish.

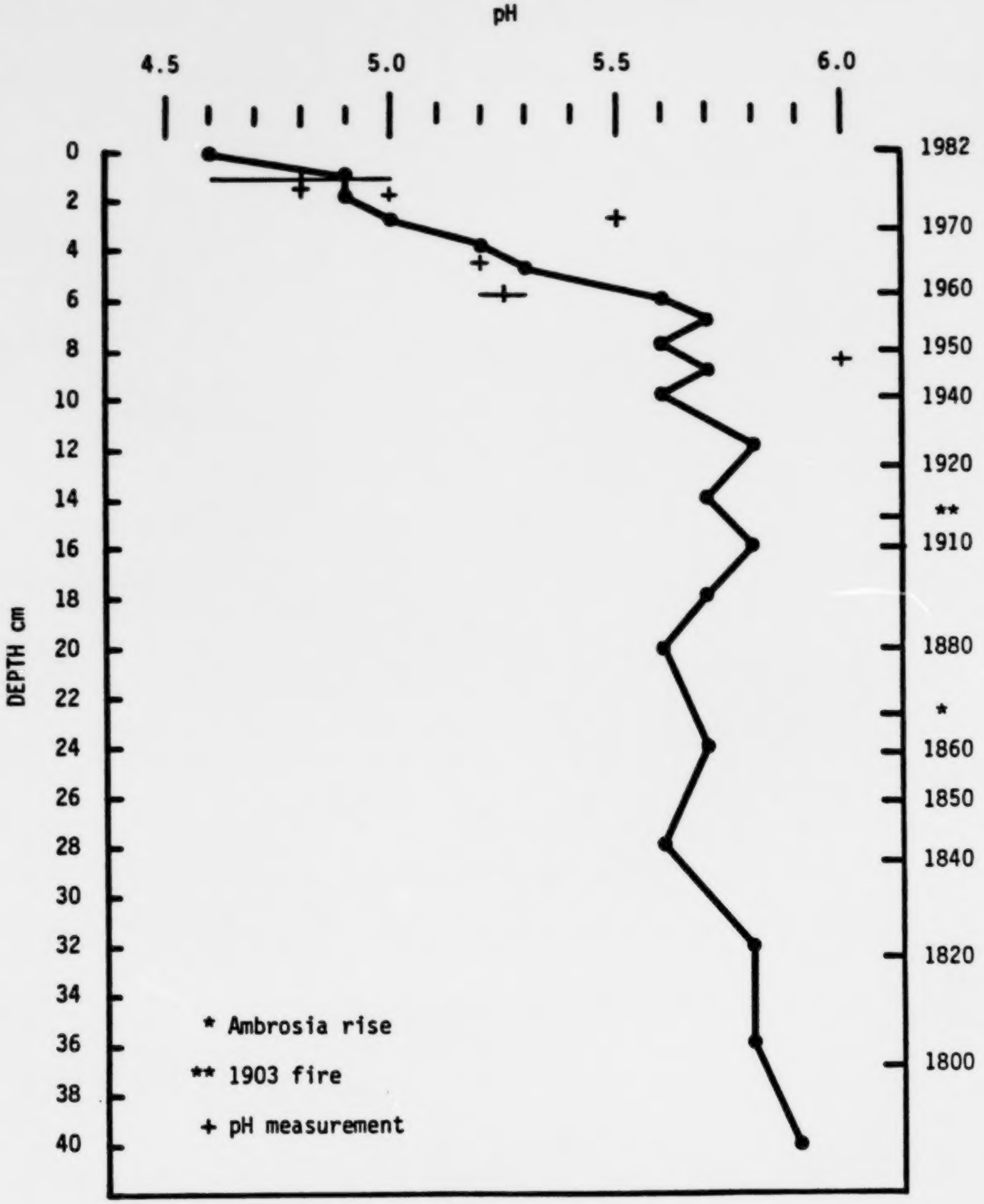

Figure 9. Profile of inferred pH for Big Moose Lake, NY, based on analysis of diatom taxa in sediment cores. Adapted from Charles (1984).

All lakes now devoid of fish need not, however, have lost their fish populations as a result of acidification. A portion of these lakes never sustained fish populations. In addition, if earlier fish populations have disappeared, it must be demonstrated that acidification was the cause.

For 40 of the high elevation lakes surveyed in 1975, historic records on acidity and fish populations were available for the 1930's (Figure 4) (Schofield 1976b). In 1975, 19 of these 40 lakes had pH levels below 5.0, and also had no fish. An additional two lakes with pH 5.0 to 5.5 also had no fish. Thus 52% had no fish. In the 1930's, only 3 lakes had pH < 5.0 and, again, none of these had fish at that time. One additional lake with pH between 6.0 and 6.5 also had no fish. Thus, in the 1930's, only 10% of the 40 lakes had no fish. This implies that 17 lakes (or 42%) lost their fish populations over the 40-year period. This loss of fish populations was correlated with an apparent increase in lake acidity, but Schofield (1976b) did not examine alternate explanations for the loss of fish in these 17 lakes. These data, however, published by Schofield in 1976, still represent the best evidence that acidification has adversely affected fish populations in the Adirondacks.

In 1980 (Pfeiffer and Festa 1980), the New York State Department of Environmental Conservation (DEC) published their first assessment of the acidity status of Adirondack lakes. The report focused on chemical data, but also provided the following statements on the status of fisheries:

> "Current resource inventory estimates indicate that at least 180 former Adirondack trout ponds, representing some 7130 acres (2886 ha), have succumbed."
>
> "In the Adirondack region, a number of former bass lakes, including Woodhull Lake, Big Moose Lake, and Canada Lake have lost their smallmouth populations in the recent past and reproductive failure associated with increased acidity is suspect."
>
> "Our latest updated resource inventory determined that nearly 11,000 acres (4452 ha) of water have reached the "critical" state of acidification (i.e., pH < 5.0). Since much of this acreage represents remote former brook trout ponds, it is considered likely that both angling pressure and resulting yields would have been considerably below the Adirondack Zone average and a reduced yield expectancy of two pounds/acre/year (2.2 kg/ha/year) is postulated. This exercise generates an estimated loss yield of some 22,000 pounds per year (9980 kg per yr) which can be attributed to atmosperic acidification."

Unfortunately, the basis for these statements was not clearly defined, nor were the fisheries data in support of these conclusions presented, except for case histories on 13 selected Adirondack lakes. The conclusion that 180 lakes have lost brook trout populations has been widely quoted. Presumably there are 180 lakes for which recent (1970's) fish sampling efforts have yielded no fish and for which historic records of fish surveys (1930's to 1960's) are available that indicate the presence of fish in earlier years. Because the names of these lakes were not published and the data were available only in DEC files, this important conclusion could not be critiqued or validated.

DEC reports published since 1980 have provided no additional details on estimated numbers of fish populations lost in the Adirondacks, apparently as a result of acidification. Colquhoun et al. (1981 and 1984) did, however, summarize available DEC data on the correlation between fish presence or absence and pH values in lakes (Table 3) and streams (Figure 10).

Table 3. Summary of Fish Distribution by pH Class for 289 Lakes with Concurrent Fish Surveys and Water Chemistry (1975-1982). (Source: Colquhoun et al. 1984).

	pH Classification		
	< 5.0	5.0 to 6.0	> 6.0
All waters sampled	33	93	163
Waters without fish	13	5	6
Waters with only non-trout species	5	11	35
Waters with trout/salmonid species	15	77	122

It is also necessary to demonstrate that the loss of fish from Adirondack lakes has occurred as a result of acidic deposition and/or acidification of surface waters. Retzsch et al. (1982) argued that "although precipitation acidity cannot be excluded as a possible cause, it represents only one of a number of factors that may alter fish populations in the Adirondacks", and that the 1980 DEC report (Pfeiffer and Festa 1980) had not adequately considered these alternate explanations for loss of fish in their assessment of numbers of brook trout populations lost or estimate of loss in yield. In particular, Retzch et al. (1982) considered that the following factors have played significant roles in the decline and loss of fish populations in the Adirondacks:

- Natural acidification and natural environmental conditions (e.g., low oxygen concentrations) responsible for the absence of fish in some waters.

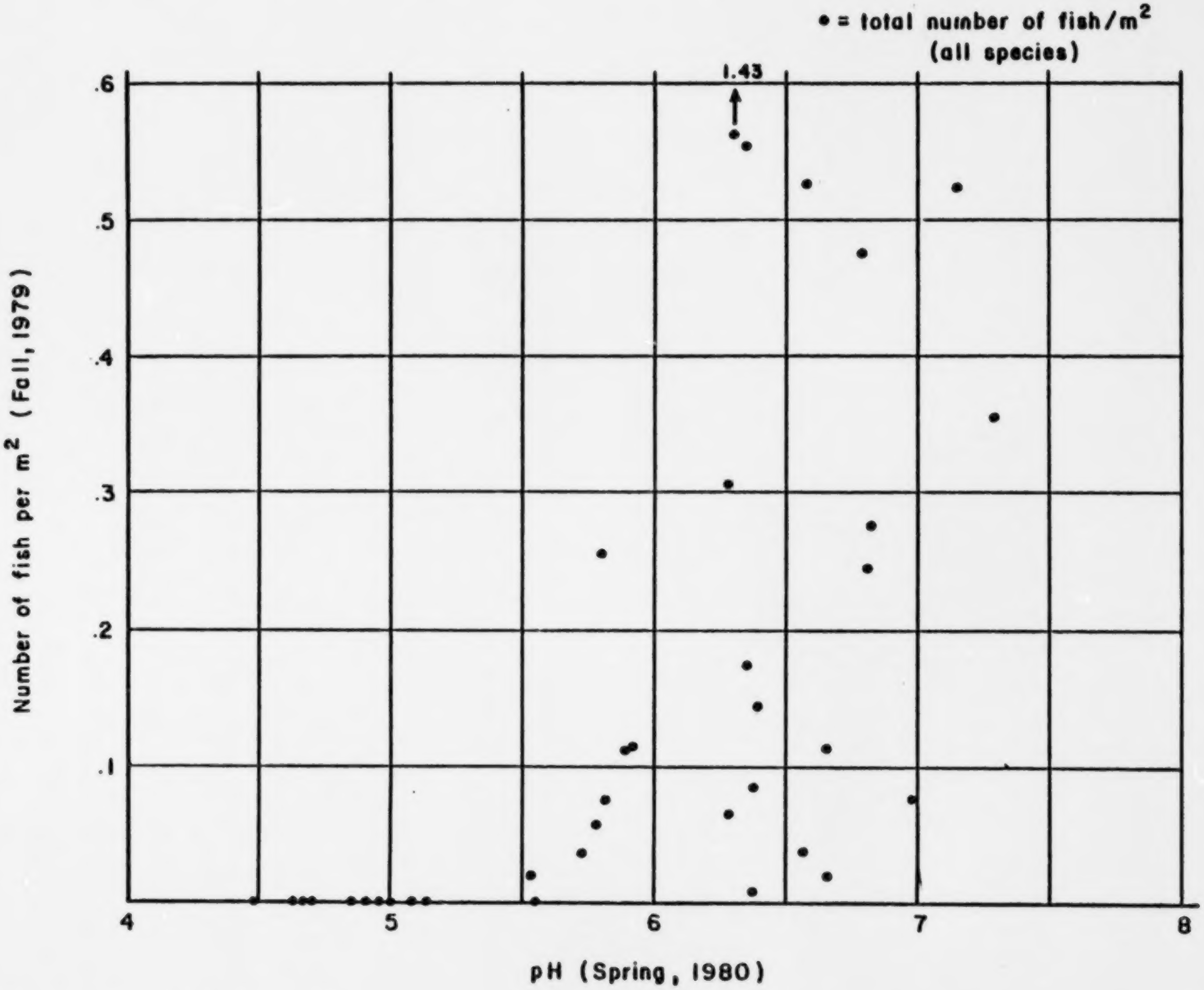

Figure 10. Number of fish caught per stream reach as a function of the minimum pH measured in the stream during the spring, 1980 (Source: Colquhoun et al. 1981).

- Changes in fish stocking and management efforts through time, in particular, the decline in numbers of fish reared annually for stocking in the Adirondacks and the decline in number of lakes stocked.

- Introductions (accidental or otherwise) of non-native fish species (e.g., yellow perch) that may prey upon or compete with native populations in the lakes.

- Increases in fishing pressure over the last several decades.

- Alteration of natural habitats resulting from construction of dams (man-made or beaver) that can eliminate fish spawning areas, block fish migrations, or create unfavorable physical/chemical conditions for fish.

- Forestry practices that can alter water chemistry and cause erosion and siltation problems.

Certainly all of the above can result in the decline or loss of fish populations. Unfortunately, Retzch et al. (1982) did not attempt to quantify the importance of these factors, as compared to acidification or acidic deposition, in controlling the current status of fish populations in the Adirondacks.

In 1982, in testimony to the Senate Committee on Environment and Public Works, the New York DEC rebutted the comments of Retzch et al. (1982), noting that loss of fish has occurred in the absence of alternative explanations other than acidification of surface waters, specifically:

- "The reduction in fish stocking programs and changes in fish management are not responsible for the loss of fish communities from acidified waters"

  - Non-game species, not maintained by stocking have also been lost.

  - Trout populations maintained by natural reproduction (never stocked) have also been lost from acidified waters.

  - Many waters have been shown by in situ bioassay to be acutely lethal to stocked fish. In these cases, and in lakes where stocking has recently resulted in poor or no returns, the stocking programs have been terminated.

- "The inadvertent introduction ... of non-native fish species ... has occurred (principally) in accessible low elevation ponded waters which are generally not currently impacted critically by acidification. Most of these larger, low elevation waters currently support fishable populations of warm water game fish."

- Increased fishing pressure is not the cause of the loss or severe reduction of fish populations in acidified waters.
  - Many waters in the immediate proximity of high-use public campgrounds have maintained excellent fish populations despite continuous heavy fishing pressure.
  - There is no evidence for any substantial increase in fishing pressure in remote areas where most of the acidified waters are documented. Restrictions on the use of mechanized equipment in some areas in the early 1970's has actually reduced fishing pressure. In addition, the season of peak recreational usage does not coincide with the seasons for peak fishing success.
- There is no apparent relationship between the distribution of acidified Adirondack lakes and the occurrence of naturally acidic wetlands.
  - Acidified lakes occur primarily in the upland western regions (as a result of regional variations in geology and deposition); naturally acidic bog ponds are found throughout the Adirondacks, but occur primarily in the northern outwash plains.
  - Fish have been lost principally from clear-water lakes low in organic acids.

Again the DEC (1982) provided only a qualitative discussion of the relative importance of various factors that may have affected fish populations.

Publications that have considered the role of acidification in the decline and loss of fish populations in the Adirondacks have: (1) been restricted to a relatively small subset of lakes (40) (Schofield 1976b), (2) presented conclusions and estimates of number of lakes impacted with insufficient explanation or background data (Pfeiffer and Festa 1980), or (3) discussed the problem in only general, qualitative terms (Retzch et al. 1982, NY DEC 1982).

II. OBJECTIVES AND HYPOTHESES

Specific questions of interest relative to assessment of potential effects of acidic deposition on the Adirondack region are listed below, and provide the basis for organization of the report. Clearly, the available Adirondack data are not adequate to fully answer each of these questions. We have, however, attempted to address these issues to the extent possible within the constraints and limitations of the existing data base. These limitations are reflected in the specific hypotheses to be tested, and discussed further in subsequent sections.

1. Are there major problems with data quality or quantity that may bias results?

2. How many acid lakes are there in the Adirondacks?

3. Is there a significant positive correlation between acidity status and concentrations of dissolved organics, suggesting that the large number of acidic lakes in the Adirondacks results principally from organic acids and natural acidification processes?

   H_o: In Adirondack lakes there is no significant correlation between pH and concentration of organic acids.

      H_1: Low pH levels in Adirondack lakes are associated with high concentrations of organic acids.

      H_2: Low pH levels in Adirondack lakes are associated with low concentrations of organic acids.

   H_o: Current pH levels in lakes low in organic content (clear-water lakes) are not significantly different from current pH levels in lakes with high concentrations of dissolved organics (lakes colored light brown or brown.

      H_1: Current pH levels in highly colored lakes are significantly lower than current pH levels in clear-water Adirondack lakes.

   H_o: The proportion of lakes classified as highly colored, and thus likely to have high concentrations of dissolved organics, is not significantly correlated with lake pH.

      H_1: The proportion of lakes classified as highly colored increases with decreasing lake pH.

4. What proportion of acidic lakes have high concentrations of dissolved organics?

5. Is there evidence that pH levels in Adirondack lakes have decreased over time?

   H_o: For Adirondack lakes overall, pH has not changed over time, i.e., the regional trend coefficient ($\bar{b}_1$) is not significantly different from zero (where b_1 is calculated from the linear model pH = $b_o + b_1$ (time)).

   H_1: The regional trend coefficient ($\bar{b}_1$) is significantly less than zero.

   H_o: The regional trend coefficient ($\bar{b}_1$) for high elevation (> 610 m) Adirondack lakes is not significantly different from zero.

   H_1: The regional trend coefficient ($\bar{b}_1$) for high elevation Adirondack lakes is significantly less than zero.

6. Have changes in pH over time occurred independently of concentrations of organic acids, suggesting that lakes with high and low levels of organic acids are equally susceptible?

   H_o: Changes in pH over time ($\bar{b}_1$) have been similar in clear-water lakes and highly colored lakes.

   H_1: Changes in pH over time have been greater in clear-water lakes than in lakes colored light brown or brown.

   H_2: Changes in pH over time have been greater in lakes colored light brown or brown than in clear-water lakes.

7. Is there evidence that Adirondack fish communities have been adversely affected by acidification?

   H_o: The status of fish communities in Adirondack lakes (ranked on an ordinal scale 0 to 5) varies independently of lake pH and changes in pH over time.

   H_1: Fish community status (ranked on an ordinal scale, 0 to 5) is negatively correlated with lake pH and changes in pH over time.

8. What is the functional relationship between fish community status and lake pH?

9. Does the presence of high concentrations of dissolved organics modify the relationship between fish community status and lake pH?

   H_o: The relationship between fish community status and lake pH is identical in clear waters, presumably with low concentrations of dissolved organics, and in waters classified as light brown or brown, indicative of high concentrations of dissolved organics.

H_1: Fish communities are adversely affected at higher pH levels in clear waters than in waters classified as light brown or brown.

10. How many fish communities have been adversely affected by acidification in the Adirondacks?

11. Is there evidence that fish populations have been lost from Adirondack lakes as a result of acidification?

H_0: Ratings of fish population status vary independently of lake pH and/or changes in pH over time.

H_1: Ratings indicating the likelihood that observed decline and/or loss of a fish population resulted from acidification increase with decreasing pH level and/or decreases in pH over time.

12. How many fish populations have been lost from Adirondack lakes apparently as a result of acidification?

13. What is the relationship between fish population status and lake pH and water color?

III. METHODS FOR ASSESSMENT OF FISH POPULATION STATUS

Our objectives are to evaluate the effects of acidification on fish populations in Adirondack lakes. Others, particularly, Schofield (1976a) and Colquhoun et al. (1984) have noted that current fisheries status (presence or absence of fish species) and present-day pH levels are correlated. Reckhow et al. (1984) have further quantified this relationship using the FIN data base as part of NAPAP project E3-02. In contrast, our task has been to assess changes in fish population status over time and the degree to which these changes have occurred as a result of lake acidification. Interpretation of Adirondack fisheries data has involved principally a lake-by-lake assessment of the evidence for loss or decline of fish populations and of alternative explanations for apparent changes in fish communities with time, including shifts in stocking policy, other fisheries management practices, and habitat alteration, in addition to acidification. Reasons for acidification (e.g., acidic deposition) have not, however, been specifically evaluated.

Ideally we would like to define an objective, quantitative measure of the change in fish population status over time. Examples include catch per unit effort, and changes in catch per unit effort over time, or the frequency of catch or no catch for a given species in a series of samples over time. Each of these, however, requires some assumptions about the consistency of fish sampling techniques such that a standard unit of effort can be defined for catch per unit effort or the probability of catch or no catch varies principally as a function of the abundance of the population in the lake. Unfortunately such is not the case for the existing Adirondack fisheries data. Sampling techniques and procedures have varied widely both over time and among lakes. Although gill nets and/or trap nets were the primary gears used in most surveys, nets were of different size, set at different times of the year, etc. To a certain extent, general gear characterizations have also changed over time, e.g., the shift from gill nets made from cotton to nets of monofilament nylon. Surveys were conducted as appropriate to the immediate needs of the fisheries biologist, ranging from a general survey of fish species present to specific collection of individual species to confirm stocking success, measure growth, or collect eggs. The effect of these variations in sampling techniques and procedures on survey results must be considered. Even with standardized sampling techniques, results from fisheries surveys are highly variable. In addition in many cases details on sampling techniques were not recorded.

As a result, we do not feel that simple quantitative measures such as catch per unit effort or probability of catch or no catch can be used to accurately express changes in fish population status over time. Instead we have defined semi-quantitative indicators of population status (i.e., an ordered classification) that incorporate the uncertainties associated with varying, and at times unknown, sampling techniques. Ordered classifications are commonly used whenever different degrees of some phenomenon can be recognized but not expressed with a standard unit of measurement on a continuous scale (Snedecor and Cochran 1976, Kleinbaum and Kupper 1978); procedures for statistical analysis are well established.

Assessment of Adirondack fisheries data involved three phases: (1) evaluation of fish population status, (2) evaluation of possible explanations for observed population declines or losses, and (3) analysis of statistical associations between loss or decline in fish populations and chemical variables indicative of acidification or acidity status (e.g., pH or change in pH over time).

Phases 1 and 2 required assignment of semi-quantitative indicators to express the status of a fish population (changes in abundance, age structure, or presence/absence over time) and the likelihood that an observed loss or decline in a population resulted from acidification. For each lake all relevant data available in FIN were reviewed and the indicator assigned reflects the best judgment of the evaluator, on an ordered scale, concerning conditions within the lake. Recommended ratings, based on a series of criteria, were pre-established as guidelines for each evaluation, to improve consistency in classifying populations. These rating systems are described in more detail below. All lakes were evaluated by the principal investigator, Joan P. Baker. For both phases 1 and 2, lakes were evaluated blindly, i.e., with no information on lake identity, water chemistry, or acidity status. Lakes were reviewed in a haphazard order to minimize the potential for trends in assignment of indicator ratings.

Evaluations were limited to 14 species considered reasonably susceptible to gears employed in most surveys and selected as either important game species or non-game species common in Adirondack lakes:

brook trout	*Salvelinus fontinalis*
lake trout	*Salvelinus namaycush*
rainbow trout	*Salmo gairdnerii*
lake whitefish	*Coregonus clupeaformis*
smallmouth bass	*Micropterus dolomieui*
largemouth bass	*Micropterus salmoides*
chain pickerel	*Esox niger*
white sucker	*Catostomus commersoni*
brown bullhead	*Ictalurus nebulosus*
pumpkinseed sunfish	*Lepomis gibbosus*
yellow perch	*Perca flavescens*
golden shiner	*Notemigonus crysoleucas*
creek chub	*Semotilus atromacalatus*
lake chub	*Couesius plumbeus*

For the first seven species listed above, stocking information was summarized and coded as follows:

Stocking Code	Remarks
1	No stocking on record. Species apparently self-sustaining.
2	Stocking sporadic. Occurrence of some "wild" fish likely. Population apparently supplemented by stocking.
3	Species stocked regularly. No pre-stocking information available to determine if species is native to the lake and natural reproduction is likely. Uncertain whether population is maintained by stocking or only supplemented by stocking.
4	Species stocked regularly. Pre-stocking surveys indicate the species was not present prior to initial stocking. Therefore, population considered to be maintained by stocking.

For each lake, the year in which the lake was last surveyed and the quantity of data available for assessment of trends in fish population status were also noted:

Rating - Quantity of Data	Number of Years Surveyed	Number of Years Between the First and Last Surveys
0	0	--
1	1	--
2	2	< 10
3	2	> 10
4	3	< 10
5	3	> 10
6	4	> 10
7	≥ 5	10-20
8	≥ 5	> 20

To be counted in the determination of data available, a survey had to include at a minimum one gill net or one trap net set at least overnight. Arbitrarily, lakes with only pre-1960 survey data were excluded from further analysis, and quantity of data rated as zero.

1. FISH POPULATION STATUS

In Phase I, evaluations of fish population status were based on: (1) results from all surveys of fish populations in the lake, including species, numbers, sizes, age, and sex of fish caught, as available, (2) available details on sampling techiques, including gear(s) used, gear sizes (e.g., gill net mesh, length of net), total effort (e.g., hours set) and depths fished, (3) stocking records (numbers and sizes of each species stocked each year), and (4) information on the physical conditions of the lake, including area, maximum depth, and elevation. Lakes were identified only by the station number within FIN. No information on water chemistry or acidity status was provided. For lakes that had been limed, data were provided only for years up to the initial liming. Indications that the lake had been subsequently limed were purged from the data under review.

Based on these data, in phase 1 for each lake for each species that occurs or occurred in the lake, three ratings of population status were provided, on a scale of 0 to 9 (low to high), the evaluator's confidence that: (1) the fish population has remained constant or increased in abundance through time, (2) the fish population has declined (extinction, decreased abundance, and/or reproductive failure) over time, and (3) the fish population has been lost from the lake. The "confidence ratings" express the likelihood that each of these three conditions correctly characterizes the status of the fish population in the lake. These evaluations of the status of each fish population were made without information on lake identification or specific location, water quality, fisheries management practices (other than stocking), or other data or comments that may bias the results.

Obviously a high confidence rating in the first category, that population abundance has remained constant or increased over time, implies a lack of confidence, or low confidence ratings for the second and third categories. For lakes with little fisheries data, or poor quality data, however, low confidence ratings may be assigned to each of the categories.

Specific criteria were established for rating each population, including (1) the number of years in which fish populations were surveyed, (2) adequacy of the sampling techniques and effort for each species, (3) initial abundance of the population in the lake, and (4) number of samples confirming the absence or decline of the fish population. Based upon these criteria, recommended ratings for each category of fish population status, considering the range in quantity and quality of data available, were established prior to the initiation of phase 1. These recommended ratings are summarized in Appendix Tables A1-A5. Examples of guidelines used in development of these recommended ratings include:

1. Increasing the number of samples over time increases the confidence with which trends in fish population abundance can be detected.

2. It is more difficult to confirm absence of a population than presence. Thus, the confidence with which decline or loss of a population can be detected increases principally as the number of samples confirming the absence or decline increases.

3. Increasing the total number of samples (as compared to samples confirming loss or decline) has a lesser effect on the confidence with which decline or loss of a population can be detected, by confirming the prior abundance of the species in the lake and its consistent susceptibility to standard gear.

4. Changes in abundance are difficult to detect with high confidence because of the high variability in catch per unit effort.

5. Questions about sampling adequacy have little or no effect on confidence ratings that the population abundance has remained constant or increased, but decrease the confidence with which decline or loss of a population can be detected.

6. The confidence with which decline or loss of a population can be detected decreases for species caught only sporadically in a series of samples, or species not consistently susceptible to common gear.

Designation of recommended ratings for specific conditions improved consistency in evaluating populations. Certain aspects of the evaluation procedure were still, however, subjective, particularly assessment of the effectiveness of survey techniques and procedures for each species.

2. FISH COMMUNITY STATUS

As part of phase 1, in addition to the above ratings regarding the status of individual fish species, for each lake with sufficient data a single summary rating, on a scale of 0 to 5, was assigned expressing the overall status of the fish community. Criteria for classifying community status included the number (proportion) of fish species apparently declining or lost from the lake, the quantity and quality of data available for assessing decline or loss of the populations, and the expected sensitivity of those species to acidification. By incorporating previous information (Baker 1984) on the relative sensitivities of fish species to acidification, and the observed order through time in which species within a lake were affected, the fish community status rating from 0 (low) to 5 (high) expressed not only the severity of change in community structure, but also the likelihood that the observed changes resulted from lake acidification. The essence of the fish community status rating system was as follows:

Rating	Key Community Characteristics
0	Community appears 'healthy'. Any changes in species composition through time appear random and apparently due to normal fluctuations. For lakes with only recent survey data available, species diversity is high and/or characteristic for the Adirondacks. Species considered acid-sensitive are present.
1	One or two species have apparently declined in abundance and/or disappeared from the lake. These species are not, however, considered particularly acid-sensitive (relative to other species in the lake), and it is unlikely that population declines or losses resulted from acidification.

Rating	Key Community Characteristics
2	One or two species have apparently declined in abundance and/or disappeared from the lake. The species affected may be acid-sensitive (relative to other species in the lake); thus the community decline may be a result of acidification. Neither the evidence for loss of populations nor the indications of the potential influence of acidification are particularly strong, however. A number of populations have maintained constant or increased levels of abundance over time.
3	Several species have disappeared from the lake. These species are expected to be acid-sensitive relative to other species remaining in the lake, suggesting the possibility that community decline may be a result of acidification.
4	All species or the majority of species have disappeared. Any species left are expected to be acid tolerant (e.g., brown bullhead, yellow perch). No questions regarding sampling techniques, although the absence of most species is only indicated by one sample.
5	All species have disappeared. No fish caught in two or more samples (in two or more years). No questions regarding sampling techniques.

Notice that classification of fish community status is based only on fish survey results, stocking records, and relative species sensitivity to acidity (from information in the available literature). The scale 0 to 5 was designed such that lakes rated 0 or 1 were unlikely to have been affected by acidification, lakes rated 3, 4, or 5 were likely to have been affected by acidification (i.e., no alternative explanations apparent), with higher ratings indicating higher confidence. Lakes rated 2 were marginal, with some suggestions of effects of acidification but no clear evidence or trends.

For some lakes, data were inadequate to classify community status according to the above ordinal scale. Special cases were noted, specifically when only recent survey data were available:

Rating	Key Community Characteristics
7	Lake surveyed only once. No fish (or only brown bullhead) caught. Stocking records indicate stocking of brook trout in one or more years, including the year immediately preceding the survey.
8	Lake surveyed only once. Only brook trout or brook trout and brown bullhead caught. Both of these species are considered relatively acid-tolerant. No earlier survey data available to indicate whether acid-sensitive species may have been lost prior to survey.

Rating	Key Community Characteristics
9	Lake surveyed only once. No fish (or only brown bullheads) caught. No other information available.

Each of these classes, ratings 7, 8 and 9, is considered separately in statistical analyses.

Phase 1 focused on classifying changes in fish populations over time, without specifying likely causes for observed declines in abundance, reproductive failures, or population losses. While large numbers of fish populations have disappeared or declined, only a fraction of these changes may be attributable to acidification. In phase 1, only for the summary variable, fish community status, are effects of acidification implied in the rating scale, by incorporating information on the expected sensitivities of fish species to acidification. For individual fish populations, possible explanations for any apparent decline or loss were examined as part of phase 2. Indications of fish population status and fish community status were assigned for all lakes prior to initiation of phase 2.

3. ALTERNATIVE EXPLANATIONS FOR POPULATION DECLINE OR LOSS

In phase 2, for each population assigned a confidence rating for decline and/or loss of the population greater than zero in phase 1, the likelihood that an observed decline or loss occurred as a result of acidification was expressed on an ordinal scale from 0 (low) to 9 (high). As in phase 1, relevant data from FIN were reviewed lake-by-lake, species-by-species. Evaluations of cause were based on survey results and stocking records plus written comments by field biologists recorded at the time of the survey, and information on fisheries management practices (e.g., reclamation). The written comments at times included qualitative statements on fishing pressure, yield, beaver populations, water level fluctuations, and other topics germane to interpreting survey results and status of the fish community. All reference to lake identity, water chemistry, acidity status, and liming were deleted.

The objective during phase 2 was to review all readily available information on alternative explanations for fish population declines, other than acidification. Alternate explanations considered included principally: (1) reclamation, (2) change in stocking policy (species stocked or number or size of fish stocked), and (3) introduction (accidental or otherwise) of predatory or competitive species. To the extent possible based on the written comments of the field biologists the potential effects of fishing pressure, water level fluctuations, and beaver infestations were also considered. A high rating during phase 2, expressing the likelihood that a population decline resulted from acidification, reflects therefore the absence of obvious alternate explanations for the observed change in population abundance through time. Ratings also accounted for the expected species sensitivity to acidification and the response of the fish community as a whole.

As in phase 1, specific criteria were established for rating each population, and recommended ratings outlined to ensure consistency in evaluations. Conditions appropriate for classifying populations on the ordinal scale 0 (low) to 9 (high) rating the likelihood that an observed decline or loss of a fish population resulted from acidification (i.e., the absence of obvious alternative explanations) were as follows:

Rating	Remarks
0	Lake reclaimed. Loss of population a result of reclamation.
1	Species clearly maintained by stocking (non-native species; natural reproduction unlikely). Stocking discontinued as a result of change in stocking policy. Other species stocked still abundant.
2	Species never abundant in the lake. Apparent disappearance (or decline) of the species very likely a reflection of sampling inefficiencies. For example, species captured only with seine in earlier surveys. No seining attempted in recent surveys.
3	Species never abundant in lake. Apparent disappearance (or decline) of the species probably a reflection of sampling inefficiencies. No other shifts in the fish community indicative of acidification.
3	Species never abundant in lake. Introduction or expansion of predatory or competitive species may have resulted in decline or loss. No other shifts in the fish community indicative of acidification.
4	Species probably maintained by stocking. Stocking discontinued with no apparent previous decline in catch per unit effort. Stocking of other species continued successfully.
4	Loss or decline in species probably reflects normal fluctuations in population abundance and sampling efficiency. No other obvious shifts in fish community indicative of acidification.
4	Species stocked but never caught in lake. Stocking failure probably a result of community interactions. Number of other species already established in the lake represent potential competitors/predators for introduced species. No other shifts in fish community indicative of acidification.
5	Species perhaps maintained by stocking. Stocking discontinued with no previous decline in catch per unit effort. No other species stocked.
5	Species perhaps maintained by stocking. Stocking discontinued following apparent loss of population. Stocking of other

Rating	Remarks
	species, expected to be more acid-sensitive, however still successful.
5	Loss or decline in species perhaps reflects normal fluctuations in population abundance (or sampling problems). One or two other species in the lake have also declined in abundance and/or disappeared but still no strong indication of community decline possibly related to acidification.
5	Species stocked but never caught in the lake. Apparent stocking failure; however species stocked only once or a few times in two or more years prior to sampling.
5	Only recent survey data available. No fish caught. Lake would appear to be likely brook trout habitat (Note: this category was used only for brook trout and in statistical analyses has been treated as a special case).
6	Species stocked but never caught in the lake. Apparent stocking failure. Species stocked for a number of years immediately preceding the survey. No obvious competing or predatory species occurring in the lake.
7	Species perhaps maintained by stocking. Stocking discontinued (or still continuing) following decline or loss of population. No alternate explanations for loss of stocked population apparent, although other species, expected to be acid-sensitive, still occur in the lake.
7	Loss or decline of species accompanied by some other indications of community decline (or few species present in initial survey). No alternate explanations apparent.
8	Species perhaps maintained by stocking. Stocking discontinued (or still continuing) following disappearance of the species. No alternate explanations apparent.
8	Loss of species from lake accompanied by other indications of community decline, i.e., loss of other species expected to be acid-sensitive.
9	Definite decline or loss of entire fish community. Acid-sensitive species affected first.

The scale 0 to 9 was designed such that ratings 0 to 3 were indicative of population declines and/or loss apparently a result of causes other than acidification. Populations rated 4 or 5 were marginal. For a rating of 4, the species affected was not expected to be particularly acid-sensitive, and the majority of species appeared unaffected, but clear indications of alternate explanations (other than acidification) for the population decline were lacking. For a rating of 5 or other hand, the species affected could be acid-sensitive, and the one or two other species also experiencing a decline in abundance may also be acid-sensitive, but still the majority of the species appeared unaffected. Increasing ratings $\geq$ 6, at least for naturally reproducing populations, are indicative of population changes probably related to acidification and reflect the expected sensitivity of the species affected and decreases in community status as a whole. Rating populations maintained or supplemented by stocking was much more difficult. Reasons for discontinuance of stocking were often unclear.

The fish community status summary rating assigned during phase 1 was not re-evaluated or included in phase 2 with one exception. For lakes identified as reclaimed in the fisheries management information obtained during phase 2, fish community status rating was changed either to: (1) 6, if all population losses or declines resulted from reclamation and post-reclamation survey results provided no clear indication of current fish community status, or (2) 0, if all species declines noted during phase 1 resulted from reclamation and following reclamation a diverse fish community was re-established, including acid-sensitive species. A rating of 6 was treated as a special case (see discussion above in Section 2), denoting inadequate data for further analyses.

4. SUMMARY - ASSESSMENT OF FISH POPULATION STATUS

In summary, evaluations of fish population status and possible explanations for observed changes were conducted blindly, with no information on lake identification or specific locale, water chemistry, or acidity status. Results from fish surveys and associated information were reviewed for each lake. Codes denoting the quantity of survey data available (number of surveys over what time span) and the date of the last survey were recorded. Only lakes with post-1960 survey data were evaluated further. 758 lakes (76% of the total lake surface area in the Adirondacks) have been surveyed in one or more years (with the most recent survey post-1960); 552 lakes (57% of the total lake surface area) have been surveyed in two or more years (Figure 11). During phase 1, for each of the 14 species of interest that occurs or occurred in a given lake, three confidence ratings were assigned, on an ordinal scale from 0 (low) to 9 (high), indicating: (1) evidence that the fish population has remained constant or increased in abundance through time, (2) evidence that the fish population has declined (decreased abundance, reproductive failure, and/or population extinction) through time, and (3) evidence that the fish population has been lost. A summary rating, on a scale of 0 (low) to 5 (high), expressed the status of the fish community as a whole. Finally in phase 2, for populations that may be declining or lost (based on evaluations in phase 1), the likelihood that the observed change occurred as a result of acidification (i.e., the absence of obvious alternative explanations) was ranked on a scale 0 (low) to 9 (high).

These procedures for assessing fish population status are only semi-quantitative, based on a ranking system rather than a continuous or discrete unit of measure such as catch per unit effort or presence/absence

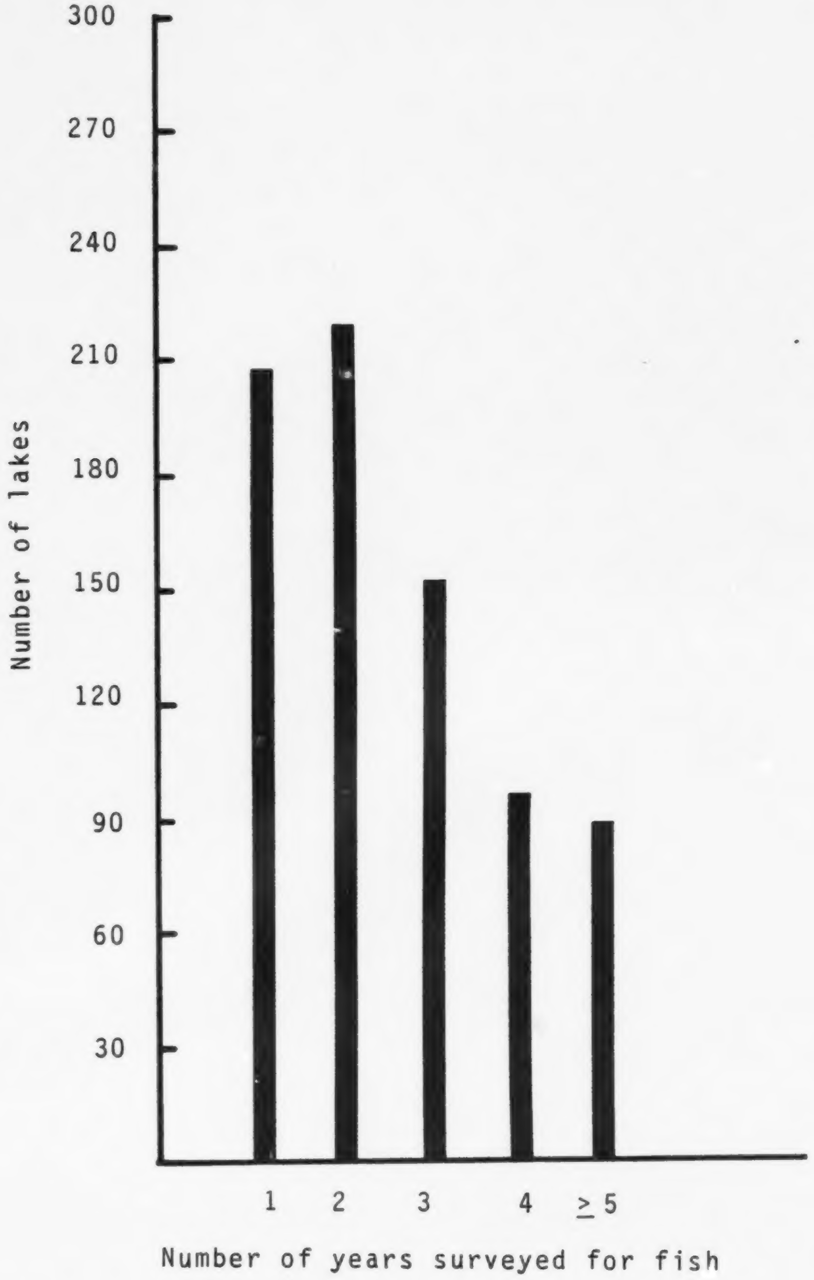

Figure 11. Frequency distribution of number of years in which fish populations were surveyed.

of the populations. Unfortunately sampling procedures have been highly variable and survey results are not amenable to quantitative analysis of changes over time. In such cases, in which different degrees of a phenomenon can be recognized but not expressed with a standard unit of measurement, ordered classification or ranking systems are commonly used and supported within the statistical literature.

Ranking systems introduce some subjectivity. Specific criteria for rating populations were established to reduce the subjectivity and improve consistency. Variations in assignment of population ratings decrease our ability to detect correlations between confidence ratings and indicators of acidity or acidification (phase 3, discussed under data analysis and results), but should not bias the results. A significant correlation between fish population status and lake acidity, although not proving cause and effect, cannot be attacked on the basis of the semi-quantitative procedures for assessment of fish population status.

IV. DATA ANALYSIS AND RESULTS

Each of the questions and hypothesis outlined previously is addressed individually in the following sections. All analyses are based on the water quality and fish survey data compiled within the FIN data base (Baker et al., 1984). Data within FIN were collected by a variety of investigators for a variety of purposes using a variety of analytical techniques. As a result, the data are often not ideally suited for use in statistical analyses. Two pervasive problems are the representativeness of the sample and variations in data quality. Imperfections in the data base often limit our ability to thoroughly resolve certain issues, but we have attempted to qualitatively and quantitatively (where possible) address these uncertainties. We believe that analysis of the existing data base, despite its imperfections, can contribute significantly to our understanding of the acidity status of lakes in the Adirondacks, and the relationship between acidification and fish population status.

1. ARE THERE MAJOR PROBLEMS WITH DATA QUALITY OR QUANTITY THAT MAY BIAS RESULTS?

Our interests focus on the effects of acidification on fish populations. Other investigators have identified four key chemical parameters that appear to control fish response to acidification: pH, aluminum, calcium, and dissolved organic carbon (DOC) (Baker 1984). Hydrogen ion and aluminum have direct toxic effects. Calcium and DOC mitigate the toxicity of hydrogen ion and/or aluminum. Thus, an analysis of Adirondack data should concentrate on some measure of fish response or fish population status (discussed in the preceding section) as a function of these four chemical parameters. Unfortunately, only for pH are sufficient data available on a broad spectrum of lakes for a balanced assessment of effects on fish. Of the 2759 lakes in the Adirondack zone, 1543 (56%) have pH data; 693 (25%) have one or more electrometric laboratory pH measurements within the last 10 years (excluding 1979) (Table 1). In contrast, only 249 lakes (9%) have values for aluminum concentration, and 86% of these are high elevation lakes (>610 m) surveyed by Schofield (1976a) in 1975. Inclusion of aluminum in analyses would thus considerably reduce the sample size (number of lakes) and perhaps bias the results by concentrating on high elevation lakes.

FIN contains no measurements of dissolved organic carbon (DOC). Neither Schofield (1976a) nor the New York DEC Bureau of Fisheries measured DOC or water color (generally correlated with DOC). DOC measurements are available for the 23 lakes included in ILWAS and RILWAS and select lakes sampled by the DEC Bureau of Water Research, but have not yet been incorporated into FIN. The number of lakes involved would still be too few for extensive analyses. Aluminum and calcium concentrations in Adirondack waters have been shown to be highly correlated with lake pH (Schofield 1976a, Reckhow et al. 1984). As a result, effects of aluminum and calcium on fish are in part incorporated into analyses based on pH. In contrast, DOC levels vary independently of pH. It is known that fish can survive at significantly lower pH levels in the presence of high concentrations of dissolved organics, presumably as a result of complexation of aluminum with organics. The absence of a measure or indicator of DOC in analyses of fish response could thus substantially increase residual variance.

Although no data are available on DOC or water color for Adirondack lakes, it is standard procedure for DEC field crews to categorize lakes as clear, light brown, brown, or dark brown. Such visual water color estimates are available for 20% (544) of the lakes within the Adirondack Ecological Zone (considering data only from 1960 to the present). Because of the importance of organics in determining fish response, these approximate and qualitative measures of visual water color have been used as indicators of the presence or absence of high concentrations of organics in some analyses. Observations from field surveys were coded as: clear (1), light brown (3), brown (4), dark brown (5). Average values <1.5 indicate lakes consistently coded as clear water, and thus are considered indicative of low levels of DOC. Average vaues >2.5 indicate lakes consistently coded light brown, brown, or dark brown, and thus are considered indicative of high concentrations of dissolved organics. Average values of 1.5 to 2.5 suggest that field crews were inconsistent in their evaluation of visual color. Lakes with average values between 1.5 and 2.5 were excluded from analyses or considered separately.

Classification of a water as clear (average value <1.5) or colored (light brown or brown) (average value >2.5) is obviously only a rough indicator of DOC. Correlation of the indicator with actual DOC measurements was, however, confirmed by Hunsaker et al. (1985) using data for Adirondack lakes sampled as part of the EPA Eastern Lake Survey, Phase I. Analyses of the effects of acidification on fish populations therefore rely principally on measurements of pH and secondarily on the visual color indicator.

The quality of pH values within FIN varies, in part as a result of different methodologies for measurement of pH. Where possible we have relied solely on pH values measured electrometrically in the laboratory with air equilibration. Prior to 1975, however, few such readings are available. Thus, for analyses which require historical pH data (prior to the mid 1970s) all pH measurements have been used, independent of method (obviously increasing the variance and uncertainties associated with these estimates). For each analysis, the type of pH used (pH meter only or all methods) is clearly delineated. Mean values are arithmetic averages of pH, not H^+ concentration.

Previous reports (e.g., Schofield 1982) have identified particular problems with electrometric pH measurements taken in 1979 by the New York State DEC. Apparently the quality of pH probe was inadequate for use in the low ionic strength waters typical of the Adirondacks. Values taken in 1979 have been reported for some lakes to be 0.5 to 1.0 pH units too low. In 1979, the DEC surveyed 396 Adirondack waters (Pfeiffer and Festa 1980). Many of these waters have never been resurveyed, so that exclusion of 1979 values from pH analyses significantly reduces sample size. Ninety lakes have both 1979 pH data from the DEC and other current (1974-1983) electrometric pH measurements. Comparison of these two values (Figure 12) supports the contention that 1979 values are consistently too low (similar

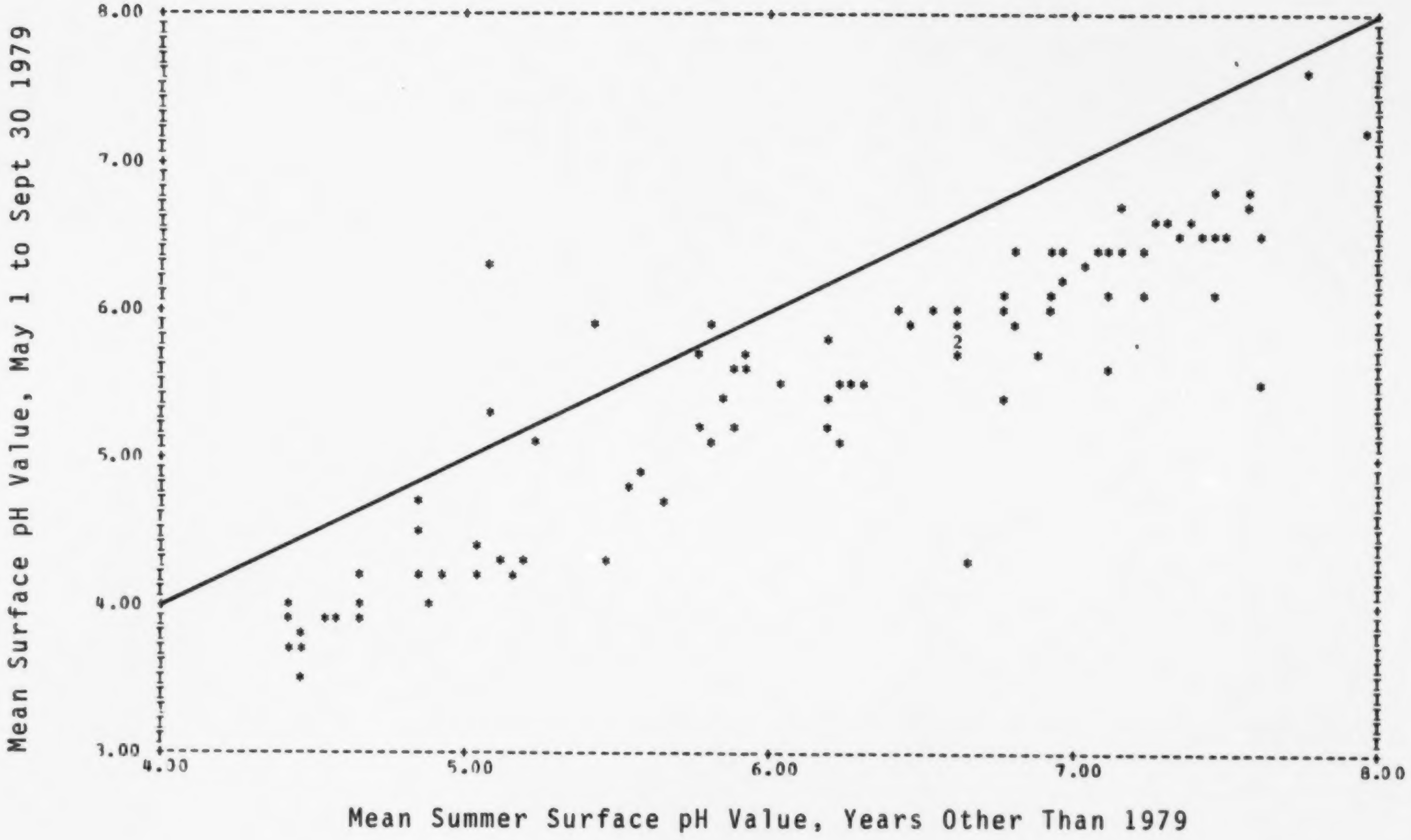

Figure 12. Comparison of pH measured in 1979 by the New York State Department of Environmental Conservation with pH values measured in 1974-1983 in years other than 1979. All values electrometric, air-equilibrated.

comparisons for other years 1974-1983 do not show similar negative biases). The deviation, pH for years other than 1979 minus pH for 1979, is fairly consistent across all values, with a mean of 0.696 pH units and standard error of 0.047. Because of the magnitude of this apparent error in 1979 pH measurements, these values have been excluded from all analyses considering pH (with one exception, as noted in the following section). Excluding 1979 DEC pH measurements, we have current (1974-1983) pH values (electrometric air-equilibrated in the laboratory) for 693 lakes in the Adirondack Ecological Zone. If 1979 values were included, data would be available for 1003 lakes.

2. HOW MANY ACID LAKES ARE THERE IN THE ADIRONDACKS?

Presumably acidic deposition has resulted in the acidification of Adirondack lakes, and an increase in the number of acidic lakes over and above that expected from natural causes. Thus, a first step in evaluating the extent of impact of acidic deposition might be to determine the extent of acidic lakes, independent of cause. The FIN data base contains chemical data on 1543 lakes in the Adirondack Ecological Zone. For the purposes of this exercise, we have arbitrarily defined acidic as pH <5.0, and based our assessment on the mean pH for a lake over the last 10 years, 1974-1983 (except 1979), using only air-equilibrated, laboratory electrometric pH values measured at 0-1 m depth during the summer period, 1 May to 30 September. Given these restrictions we have information on the current acidity status of 693 of the 2759 lakes in the Adirondack Ecological Zone (Figure 13). We wish to use this data to estimate acidity status for all lakes in the Adirondacks.

2.1. Estimates Based on Simple Proportions

Initially we assume that: (1) our 693 lakes with current pH data represent a random sample of Adirondack lakes, and (2) our indicator of acidity, pH, is measured without error. Given these assumptions, the proportion of acidic lakes (pH <5.0) in the sample (171 of 693 lakes) estimates the proportion (P_r) of acidic lakes in the total population (2759 lakes) (Snedecor and Cochran 1976):

$$P_r \pm 1.96 \sqrt{\frac{p\,q}{n}} \sqrt{1 - \frac{n}{N}}$$

where p = the observed proportion of lakes in the sample with pH <5.0

q = 1 - p

n = number of lakes in the sample (693)

N = number of lakes in the population (2759)

Since 24.7% of the lakes sampled had pH <5.0, we would estimate that 24.7%

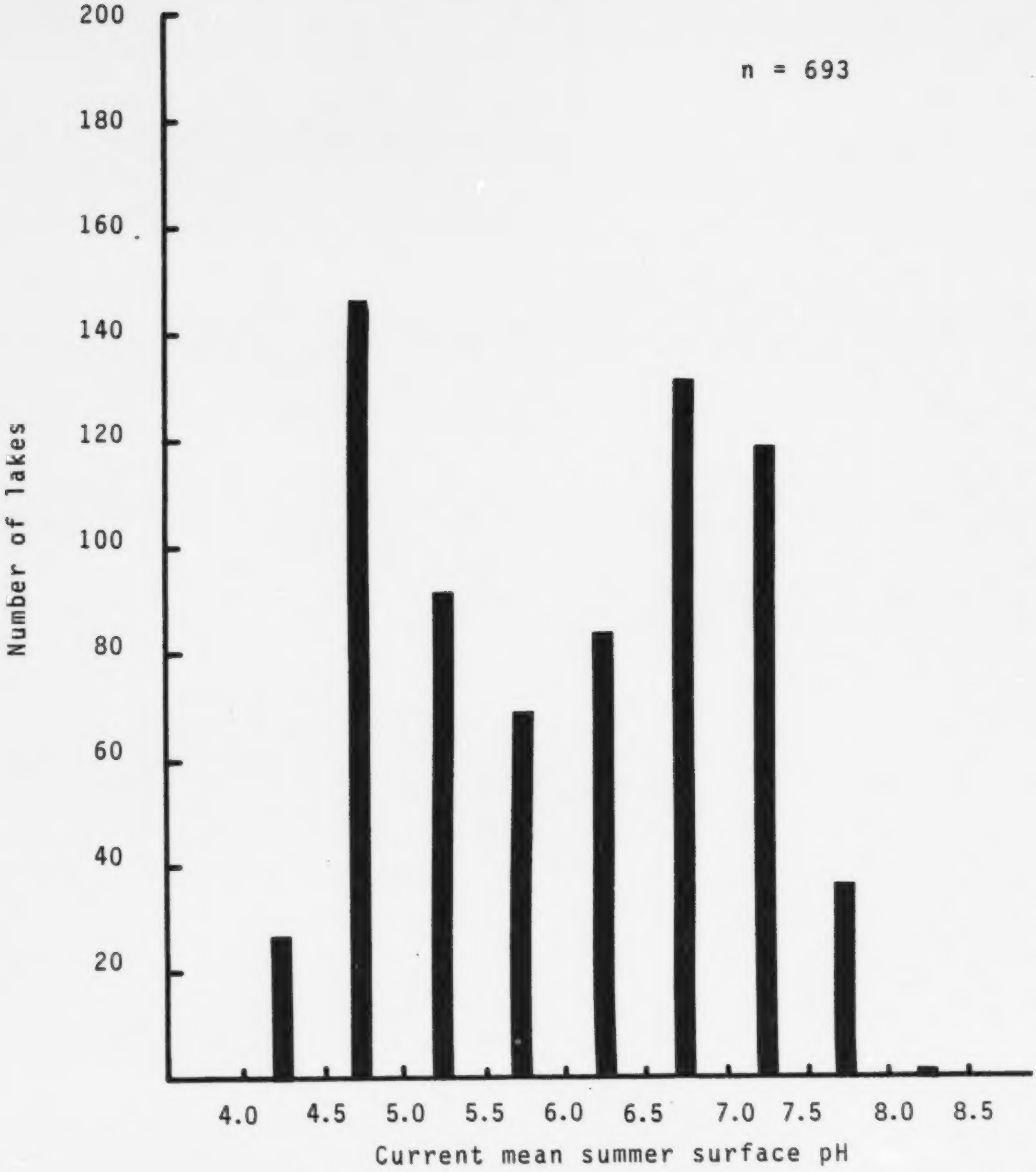

Figure 13. Frequency distribution of current (1974-1983) summer surface pH (electrometric, air-equilibrated).

($\pm$ 2.8%)* of all lakes have pH <5.0, or 681 lakes, with the 95% confidence interval:

$$P\ (604 \leq \text{number of acidic lakes} \leq 757) = 0.95$$

On the basis of lake area, lakes with pH <5.0 comprised 4.2% (2000 ha) of the total lake area in the sample (47,982 ha) (Figure 14). Thus, an estimated 4.2% ($\pm$ 1.3%) of the total lake surface area in the Adirondacks (99,666 ha) is acidic:

$$P\ (2871 \text{ ha} \leq (\text{total lake area with pH} <5.0) \leq 5437) = 0.95$$

2.2. Adjustment for Potential Sampling Bias Associated with Lake Area and Elevation

The available data, however, are not a random sample of all Adirondack lakes, and, as a result our estimates of number and surface area of acidic lakes may be in error. Can we improve these estimates by correcting for biases in the sample? The data set on current pH combines data from several investigators collected for a variety of purposes, none of which involved a random sample of Adirondack lakes. Thus we can never be certain of all the biases associated with sample selection that may have resulted in a higher or lower proportion of acidic lakes in the sample than in the Adirondack region as a whole. For example, if lakes were selected for sampling based on a priori knowledge that the lakes were acidic (perhaps from earlier measurements of pH), then our sample of 693 lakes probably contains an unusually large number of lakes with pH <5.0. Unfortunately, we have no way of confidently detecting or correcting for such a systematic bias. In many cases, however, sample selection was based not on a priori knowledge of pH but instead on factors known (or expected) to be correlated with lake pH, or more specifically the sensitivity of lakes to acidic deposition. For example, Schofield (1976 a,b) chose to sample only high elevation (>610 m) Adirondack lakes, expecting this sample to include the lakes most affected by acidification. In contrast, the tendency for the DEC Bureau of Fisheries to concentrate on lakes with productive, active fisheries has resulted in more data on the larger, more accessible lakes at lower elevations. Since we know elevation and lake area for most Adirondack lakes (91% and 88% for elevation and area, respectively), we can determine the representativeness of our sample of 693 lakes, at least with regard to elevation and lake area, and correct for this bias by either: (a) stratifying the sample or (b) using elevation and/or area as auxiliary variables in estimating the number and surface area of acidic lakes. To the extent that lake pH is correlated with elevation and/or area these procedures will also correct for biases associated with selecting lakes for sampling based on a priori knowledge of lake pH.

Frequency distributions of lake area and elevation for lakes for which we have a measure of current pH are compared in Figures 15 and 16 to

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*throughout this report, estimates of the mean will be accompanied by values for the 95% confidence interval.

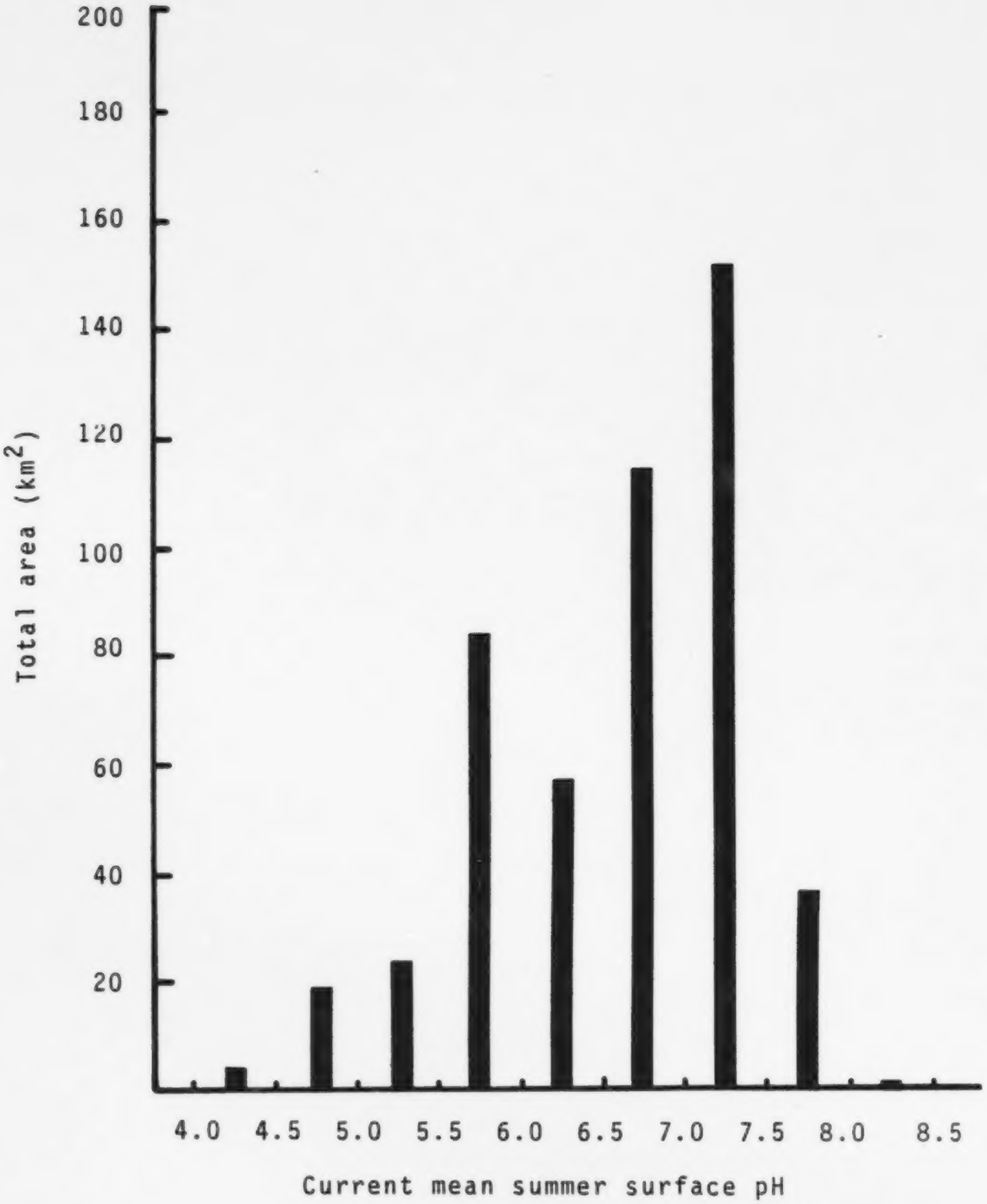

Figure 14. Frequency distribution, weighted by lake surface area (km^2), of current (1974-1983), summer surface pH (electrometric, air-equilibrated).

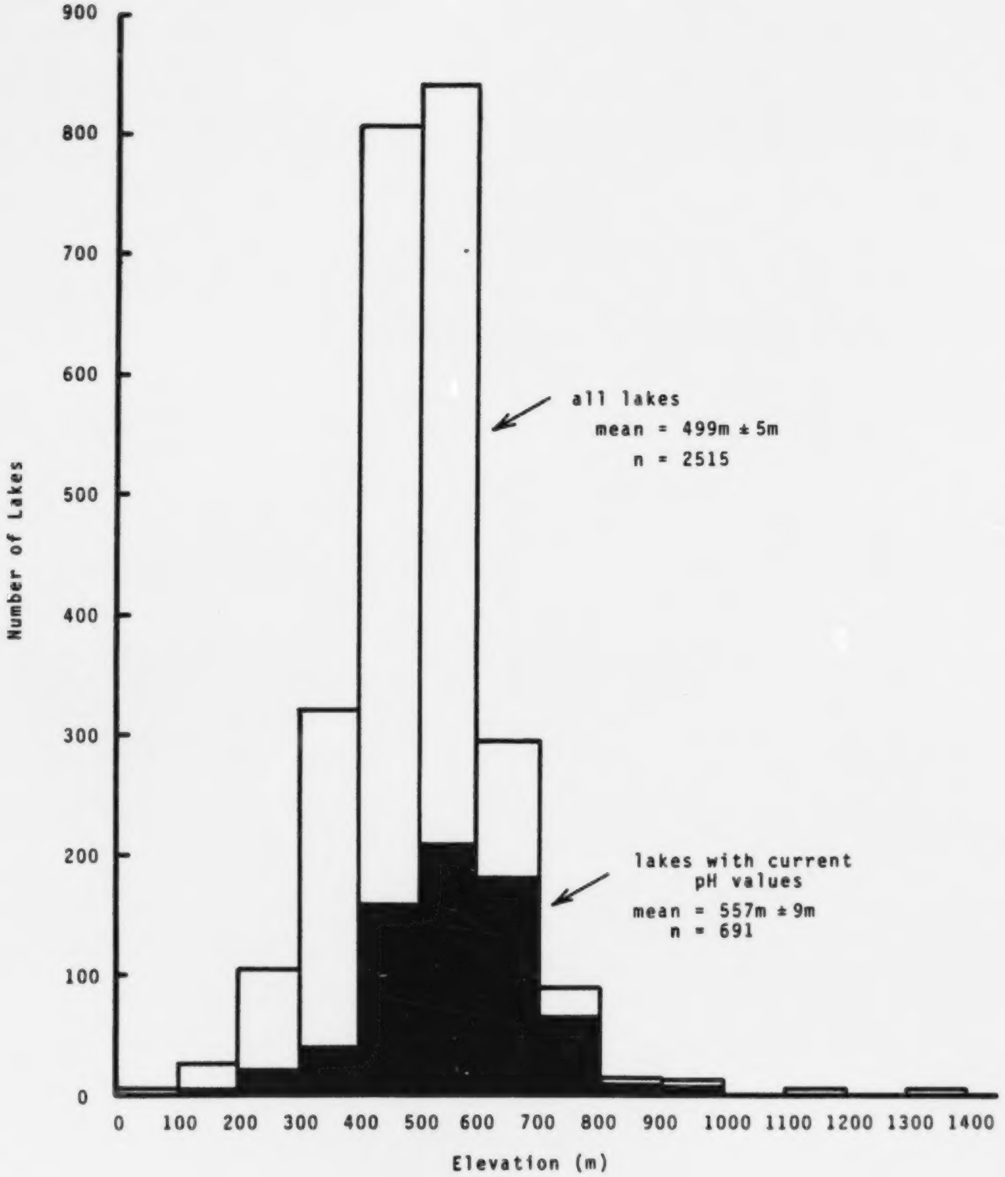

Figure 15. Frequency distribution of lake elevation.

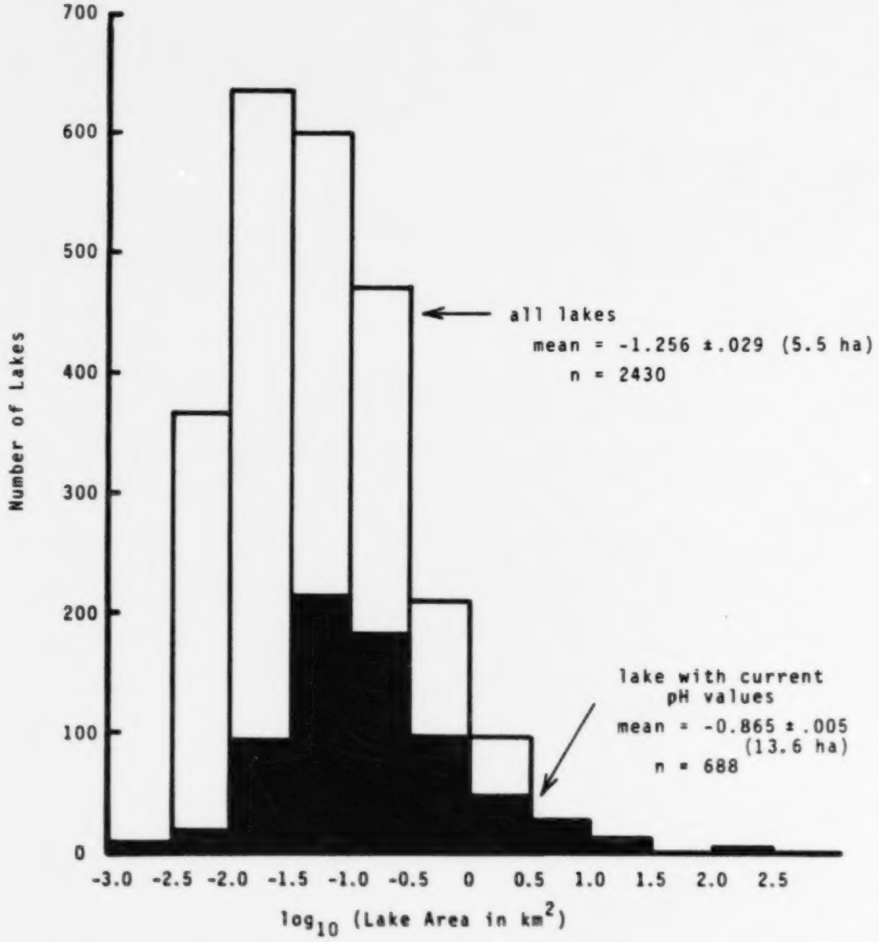

Figure 16. Frequency distribution of lake area.

similar distributions of area and elevation for all lakes in the Adirondack Ecological Zone (i.e., the 88-91% of the lakes for which we know elevation and/or area). Since the distribution of lake areas is skewed strongly toward large lakes, data have been transformed to log (area). Our sample appears biased slightly towards both lakes at higher elevation and larger lakes. Both elevation and lake area are significantly ($p \leq 0.05$) correlated with lake pH (Figures 17 and 18), suggesting that the sample bias towards larger lakes and lakes at higher elevations may have biased our estimate of the number of acid lakes. In part, however, these biases may counteract, since the frequency of acidic lakes increases with higher elevations but decreases with increasing lake size.

The simpler approach for estimating the number of acidic lakes adjusted for elevation and lake area is to stratify our sample into classes or strata. Ideally the within strata variance (of pH) should be as small as possible, and differences in mean pH between strata as great as possible. Examination of Figures 19 and 20 suggests that four strata are appropriate: (1) lakes at very high elevations (elevation ≥ 800 m), (2) lakes either very large (surface area ≥ 500 ha) or at very low elevations (elevations ≤ 350 m), (3) small lakes at fairly high elevations (surface area ≤ 50 ha and elevation ≥ 450 m, but less than 800 m), and (4) lakes of intermediate size at intermediate elevations (surface area < 50 ha and elevation between 350 m and 450 m, or surface area between 50 and 500 ha and elevation between 450 and 800 m). Within each strata, the proportion of acidic lakes in the sample is used, as before, to estimate the proportion of acidic lakes in each strata (Table 4).

Table 4. Estimated Numbers of Acidic Lakes (pH <5.0) in the Adirondack Ecological Zone

	SAMPLE		POPULATION		
STRATA*	TOTAL	LAKES WITH pH < 5	TOTAL	LAKES WITH pH < 5	95% CONFIDENCE INTERVAL
1	14	11	25	19.6	16 - 24
2	50	0	240	0	
3	482	154	1447	462.3	413 - 512
4	142	5	584	20.5	5 - 35
TOTAL	688	170	2296	502.5	468 - 537

*Strata are defined on the basis of lake area and elevation. Further details are provided in the text.

The estimated percentage of lakes with pH <5 has shifted from 24.7% (± 2.8%) down to 21.9% (± 1.5%). The change is relatively minor, perhaps because the bias towards sampling higher elevation lakes is counterbalanced by the bias towards sampling larger lakes. Of the 2296 lakes for which we have values for both elevation and area, we would therefore predict that

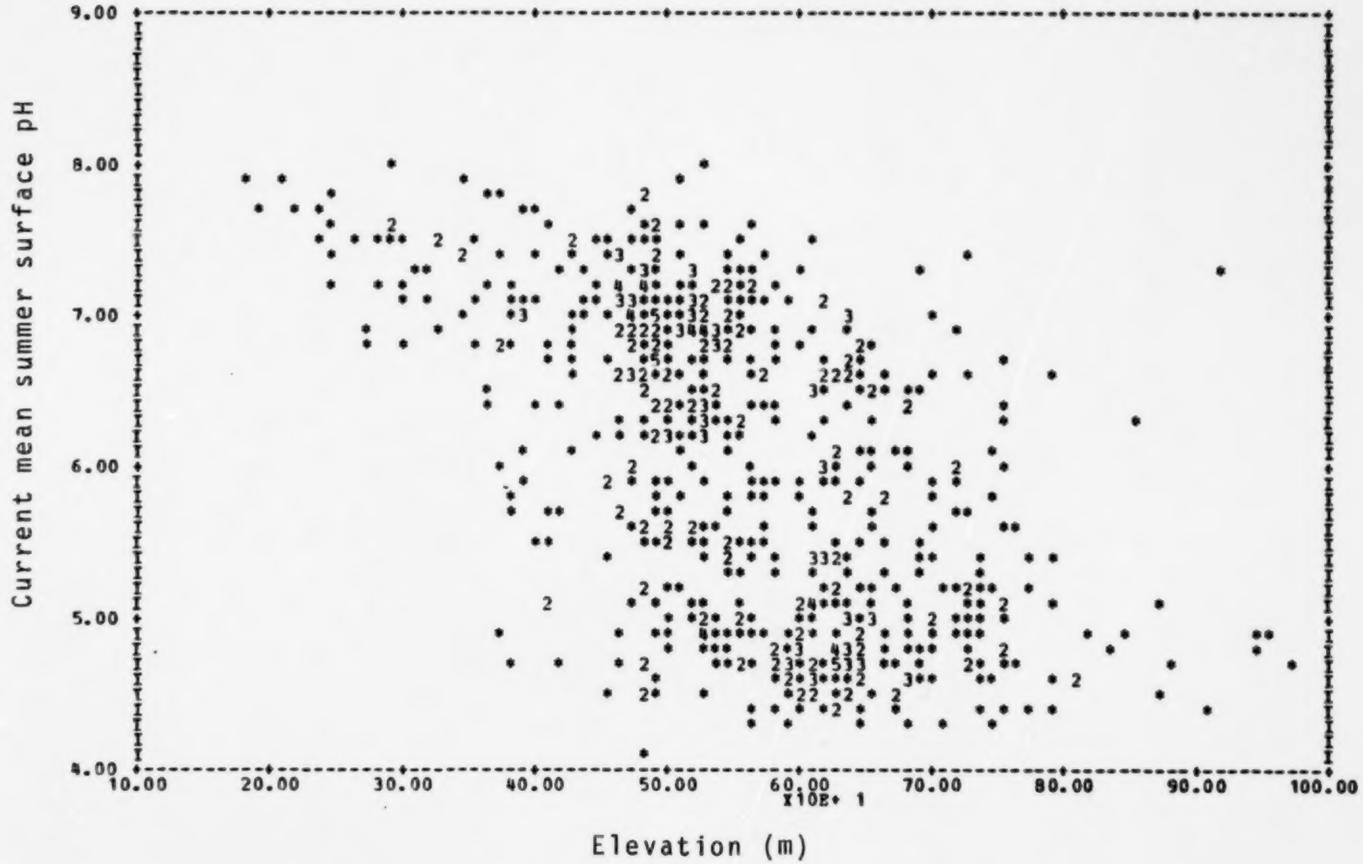

Figure 17. Current (1974-1983) mean summer surface pH (electrometric, air-equilibrated) plotted as a function of lake elevation (m).

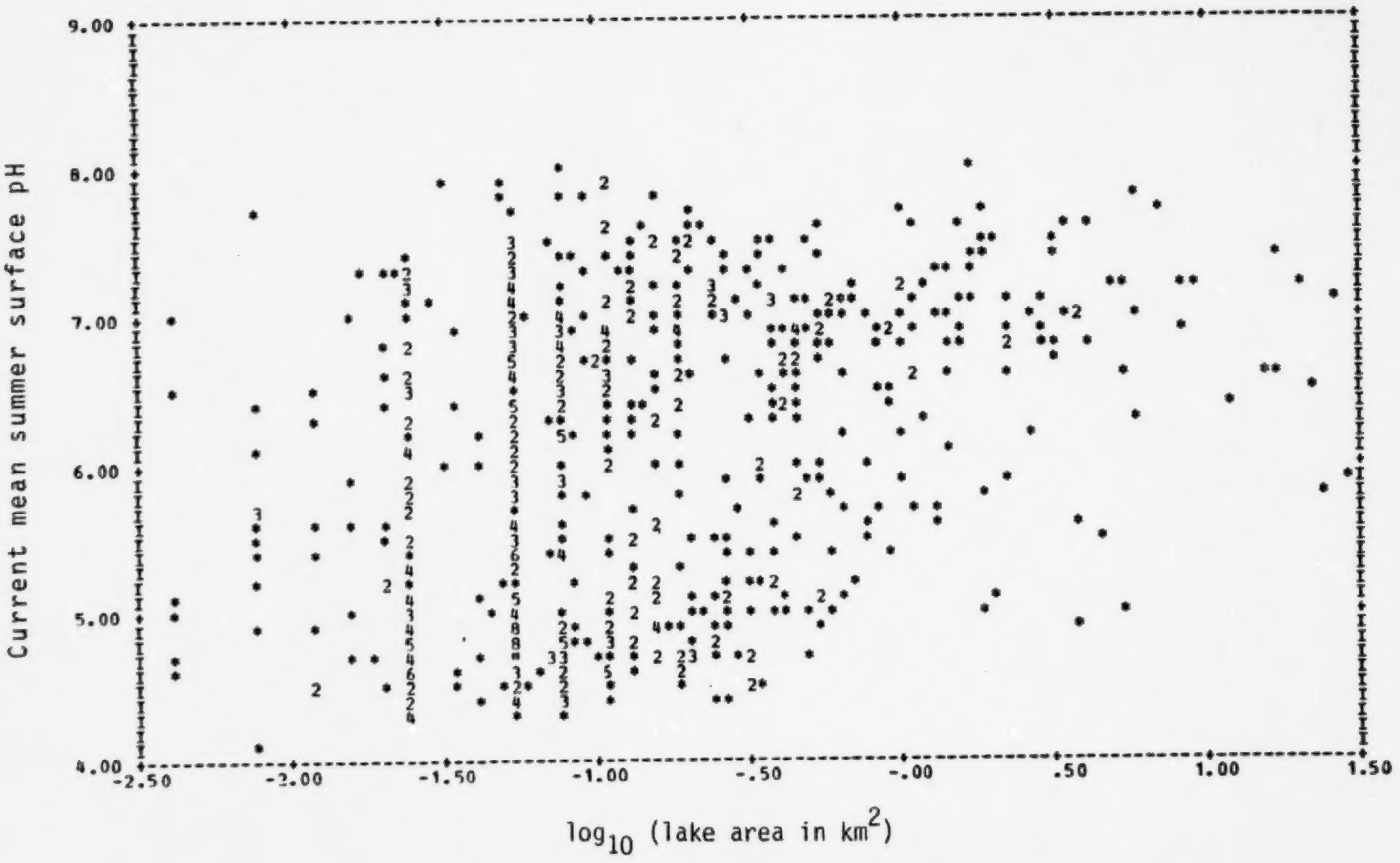

Figure 18. Current (1974-1983) mean summer surface pH (electrometric, air-equilibrated) plotted as a function of $\log_{10}$ (lake area in km^2).

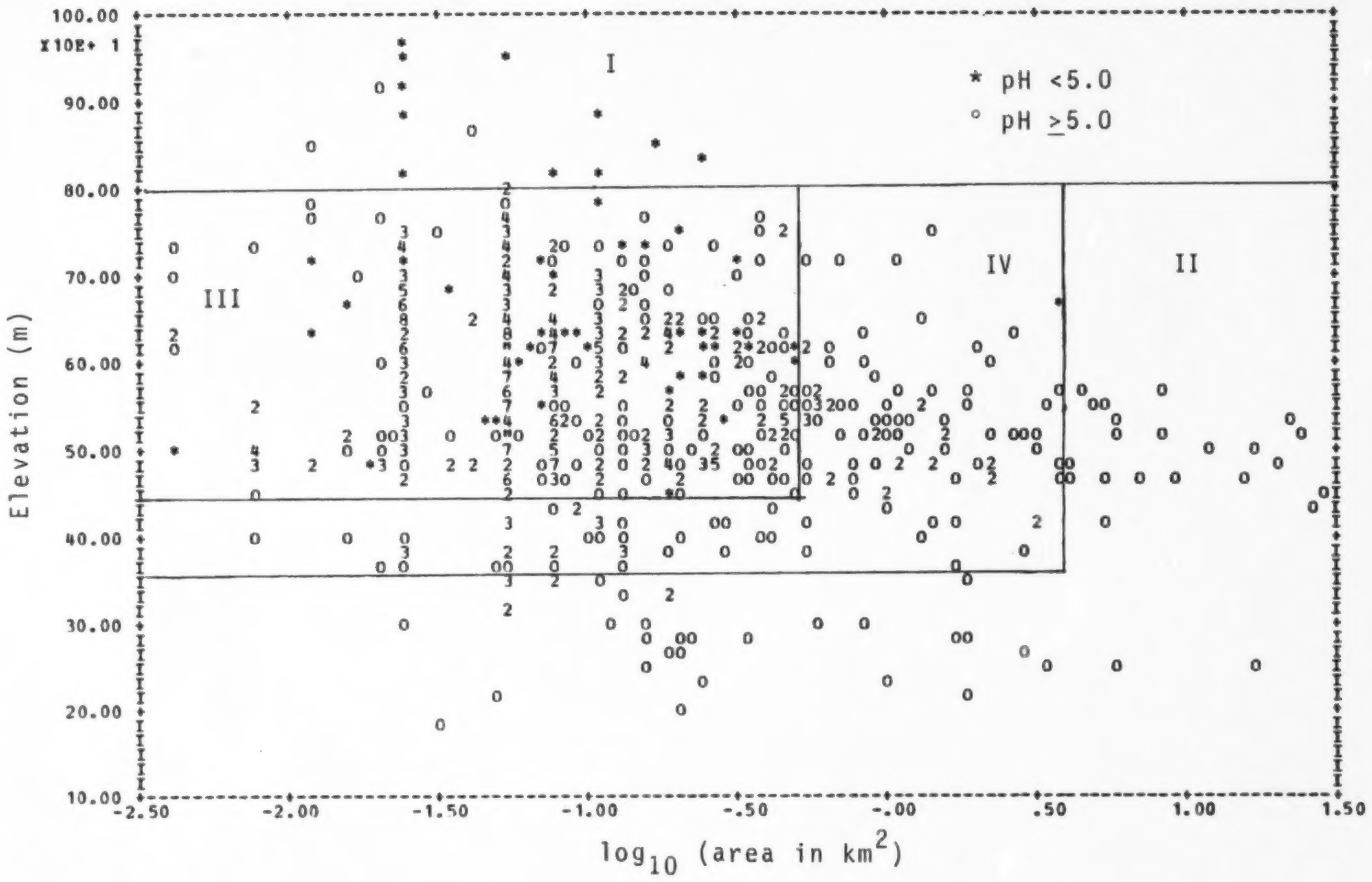

Figure 19. Distribution of acidic lakes (pH <5.0) and non-acidic lakes (pH $\geq$5.0) by elevation (m) and $\log_{10}$ (area in km^2); pH classification based on mean current (1974-1983) summer surface pH values. Four strata defined in text denoted by roman numerals. (Multiple lakes with a given area and elevation appear as numbers)

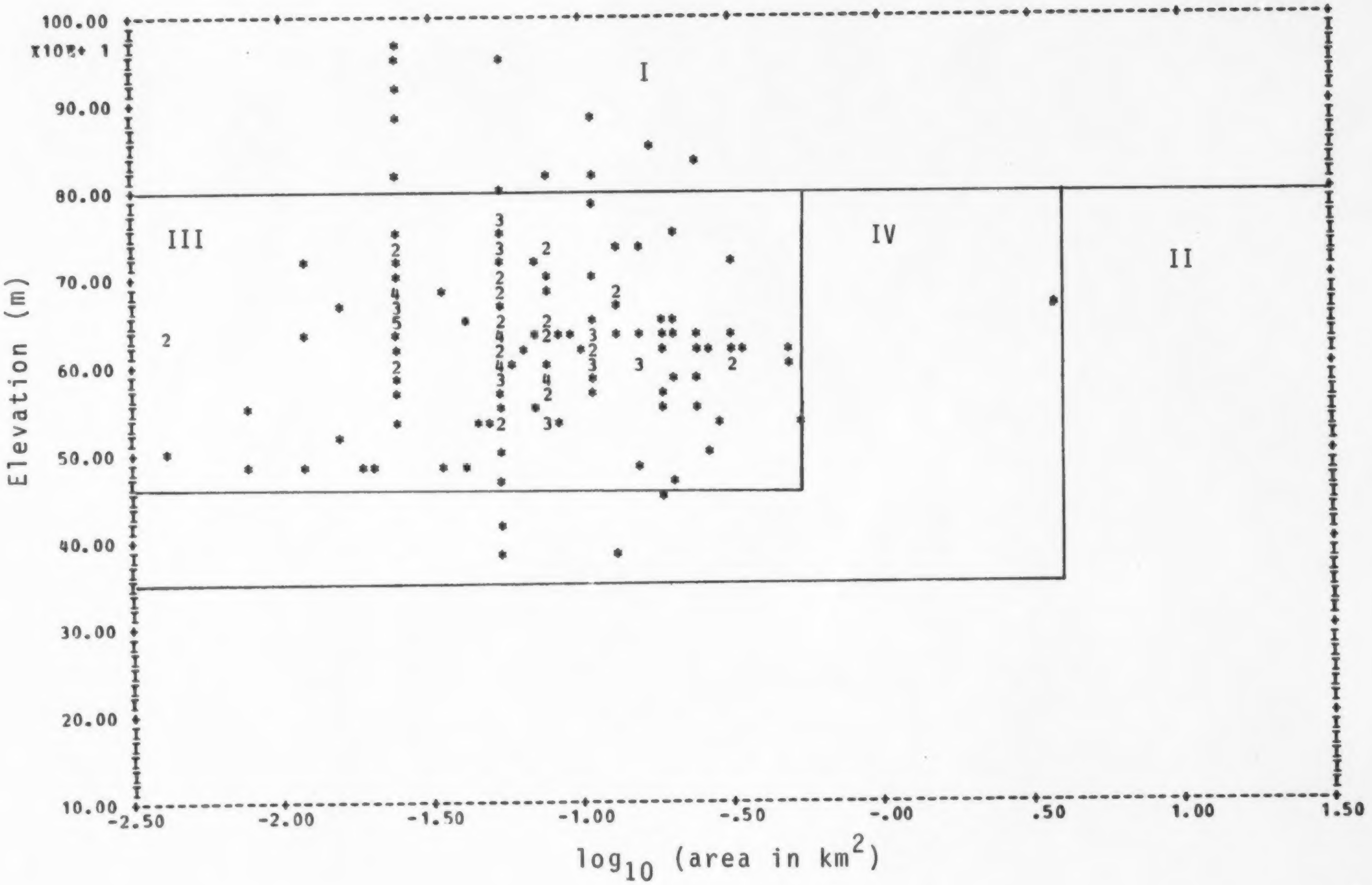

Figure 20. Distribution of acidic (pH <5.0) lakes by elevation and $\log_{10}$ (area in km^2); pH classification based on mean current (1974-1983) summer surface pH values. For strata defined in text denoted by roman numerals. (Multiple lakes with a given area and elevation appear as numbers)

about 503 were acidic, with a 95% confidence interval:

$$P\ (468 \leq \text{number of acid lakes} \leq 537) = 0.95$$

On the basis of lake area, the estimated percentage of total surface area with pH <5.0 decreases slightly from 4.2% (± 1.3%) to 4.1% (± 2.7%) (Table 5).

Table 5. Estimated Total Surface Area (ha) of Lakes with pH <5.0 in the Adirondack Ecological Zone

	SAMPLE		POPULATION		
STRATA*	TOTAL	LAKES WITH pH < 5	TOTAL	LAKES WITH pH < 5	95% CONFIDENCE INTERVAL
1	94	87	103	95	85 - 106
2	26,846	0	57,531	0	
3	5990	1457	12,753	3102	2703 - 3501
4	15,052	456	29,314	888	169 - 1607
TOTAL	47,982	2000	99,701	4085	1389 - 6781

*Strata are defined on the basis of lake area and elevation. Further details are provided in the text.

An alternative procedure for adjusting estimated numbers and surface area of acidic lakes for biases related to elevation and lake area would be through the use of regression estimates, as described by Snedecor and Cochran (1976). The bimodal distribution of pH in Adirondack Lakes (Figure 13), which results from the presence of two major buffering systems, aluminum and bicarbonate, prevents the use of standard regression procedures that would estimate pH as a function of elevation and lake area. It is possible, however, using a logistic multiple regression model to fit acidity status (pH <5 or pH $\geq$5) as a function of elevation and area, for lakes with current pH data.

$$P = \frac{1}{1+ \exp[-(b_0 + b_1X_1 + b_2X_2)]}$$

where P = the probability that a lake has pH < 5.0
X_1 = lake elevation (m)
$X_2 = \log_{10}$ (lake area in km^2)
b_0, b_1, and b_2 are regression coefficents

This logistic regression equation can then be used to predict the acidity status of all lakes with known elevation and lake area. Data for lakes within the Adirondack Ecological Zone were analyzed with the LOGIST procedure developed by Harnell (1983) and available in SAS (SAS Institute, Inc.):

VARIABLE	BETA	STD. ERROR	CHI-SQUARE	P	R
INTERCEPT	-6.461	0.606	113.8		
ELEVATION (m)	0.008	0.001	61.7	0.0000	0.279
LOG (AREA in km^2)	-9.164	0.184	24.8	0.0000	-0.172

(the interaction term was not significant)

Fraction of concordant pairs of predicted probabilities and responses=0.782
Rank correlation between predicted probability and response = 0.576

The model predicts, for each lake with both area and elevation defined, the probability that the lake is acidic (pH <5.0). The mean predicted probability for all lakes (n = 2293), 0.222, corresponds to the predicted proportion of lakes that are acidic. Thus the model predicts that 22.2% of the 2293 lakes in the Adirondacks, for which we know area and elevation*, are acidic (i.e., 508 lakes):

$$P(17.3\% \leq \text{percent lakes acidic} \leq 28.0\%) = 0.95$$
$$P(397 \leq \text{number of acidic lakes} \leq 642) = 0.95$$

Correction for potential sampling bias based on lake area and elevation therefore results in little change in our original estimate; approximately 20-25% of the lakes are predicted to have pH <5.0.

Unfortunately 463 (17%) of the 2759 lakes in the Adirondack Ecological Zone lack information on either elevation and/or lake area. For these lakes, we are unable to predict current acidity status. We cannot rule out the possibility that these 463 lakes represent a particularly unusual subset of Adirondack lakes (e.g., all very small lakes at very high elevations), although the data we have on these lakes does not support this contention. Of the 463 lakes, 219 (47%) have data on elevation; for these the mean elevation of 487 m is similar to the mean elevation (499 m) for all lakes (Figure 15). Thirty percent (137 lakes) of the 463 lakes have information on lake area; and again the mean lake area (1.0 ha, based on the log transformation) is smaller but not markedly different than the mean for all lakes (5.5 ha) (Figure 16). It is interesting to note that 351 (76%) of these lakes are unnamed.

2.3. Adjustment for Potential Bias Associated with Errors in the Measurement of pH

In addition to problems associated with potential sampling bias, our calculations of estimated numbers of acidic lakes may also be in error due to errors in the measurement of current pH. Having excluded 1979 pH values from our analysis, we have no reason to believe that our calculated mean current summer surface pH is a biased estimator of the true summer surface pH. There is, however, a certain variance associated with our estimate of current pH, and thus error associated with assessment of acidity status. Reckhow et al. (1984) discuss estimation of within-lake variability in pH for the FIN data base in greater detail.

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*Note that 3 lakes have area defined as 0.000 km^2 (i.e., less than 0.0005 km^2) in FIN and thus log (area) is undefined.

Confidence intervals reported above incorporate this uncertainty in pH or acidity status. Our calculations have not, however, accounted for any bias in estimates of numbers or percentage of acidic lakes that may result from errors in assessment of acidity status associated with within-lake pH variability. If, per chance, the true pH values for Adirondack lakes were normally distributed with a mean pH of 5.0, then the errors in assessment of acidity status would be random and the estimate of numbers of acidic lakes unbiased. If, on the other hand, pH was normally distributed but with a mean pH >5.0, then our estimate of numbers of acidic lakes would be too high. Procedures for correcting for this bias would, however, be fairly straightforward. In actuality, pH in Adirondack lakes follows a bimodal distribution, with major modes at approximately pH 4.7 and 6.5 (Figure 13; Schofield 1976a). Given this more complex distribution it is neither obvious whether our estimates are biased up or down, nor a simple process to correct for any bias.

If we can assume that the within-lake standard deviation in H^+ concentration varies roughly linearly with the mean H^+ concentration (Reckhow et al. 1984), then the direction and magnitude of the error in assessment of acidity status depends principally upon the distribution of true pH values on either side of pH 5.0 (the arbitrary boundary for defining lakes as acidic or not acidic), especially within the range $\pm t_{0.05}\ (S_{\bar{x}})$. Reckhow et al. (1984) estimated that the standard error in mean pH for lakes within FIN is approximately 0.27 pH units. Since we have excluded 1979 pH data, the appropriate standard error for mean pH for data used in this analysis is probably <0.27 pH units.

Examination of the pH data for our sample of 693 lakes (Figure 21), and consideration of the theoretical pH distribution for lakes with aluminum and bicarbonate as the major buffering components, suggest that a greater number of lakes have a true pH less than 5.0, between pH 5.0 and 4.47, $(\bar{x} - t_{0.05}\ (S_{\bar{x}}))$, than have a true pH greater than 5.0, between 5.0 and 5.53 $(\bar{x} + t\ 0.05\ (S_{\bar{x}}))$. As a result, we would propose that our estimate of number of acidic lakes is too low. On the other hand, since the majority of lakes have a true pH >5.0, even given a very low error rate for lakes with pH >5.53, a significant number of non-acid lakes (true pH >5.0) may be erroneously classified as acidic (mean observed pH <5.0) as a result of the large within-lake variance and small number of samples per lake. In this case, we would propose that our estimate of numbers of acidic lakes is too high. Quantification of the actual bias in the estimated number of acidic lakes would require statistical derivation of the theoretical probability distribution for true pH. Although this topic may be pursued further as part of project E3-02 (Reckhow et al. 1984), we have not attempted to derive this probability distribution. A qualitative review of the data, however, suggests that while certain characteristics of the distribution may result in under-estimation of the number of acidic lakes, other characteristics may

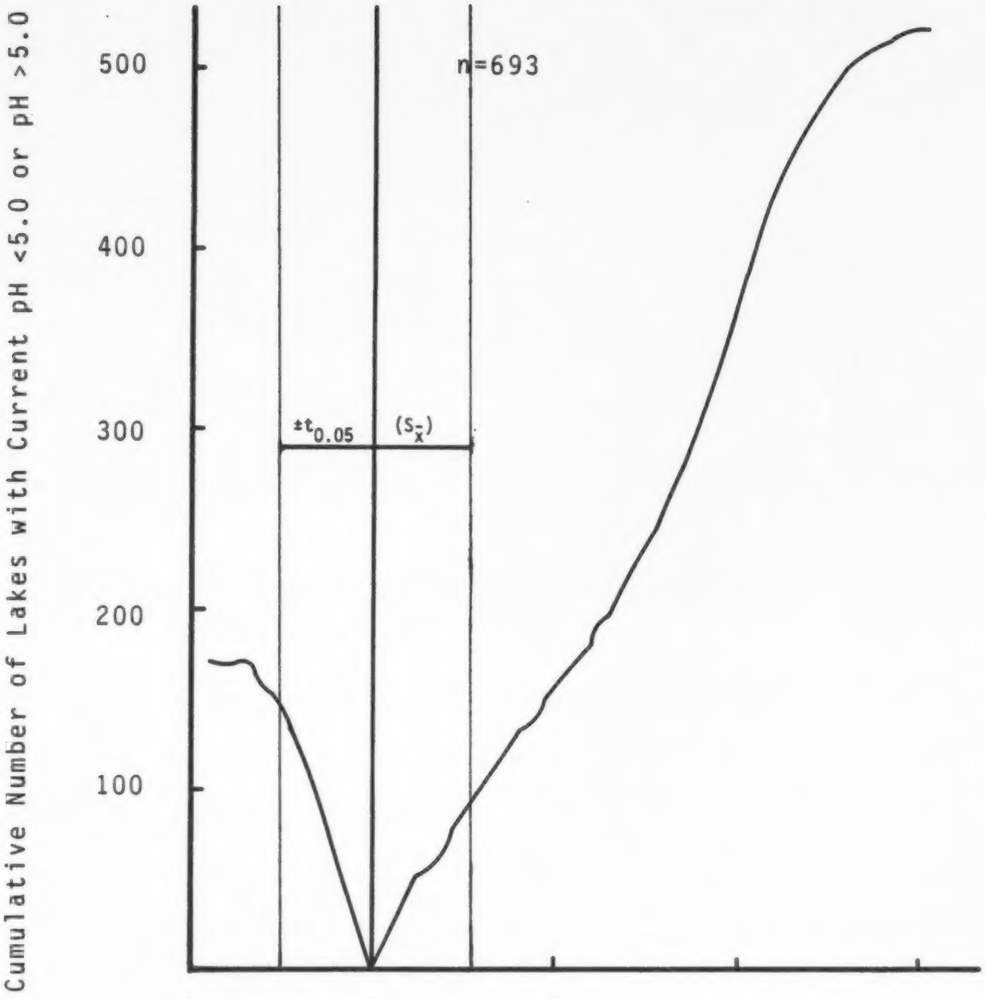

Figure 21. Cumulative number of lakes with current summer surface pH <5.0 and pH >5.0 as a function of pH.

cause the number of acidic lakes to be over-estimated. It is possible, therefore, that the bias associated with assessment of acidity status is not large.

Estimates of current pH in Adirondack lakes (Figure 13) consider only electrometric laboratory measurements of pH following air-equilibration at 0-1 m depths during the summer periods 1 May to 30 September 1974-1983. The majority of pH measurements in FIN were taken during the summer months. Since seasonal variations in pH can be quite large, a "standard" season, i.e., summer, was selected for evaluation of acidity status and the relationship between water quality and fish population status. Colorimetric and all field pH measurements have been excluded from calculation of mean summer surface pH 1974-1983 to minimize potential errors and the variance in estimates. The 1979 pH data have also been excluded, since the values appear consistently 0.5 to 1.0 pH units too low (Figure 12). Restriction of the data set to air-equilibrated laboratory electrometric pH measurements in years other than 1979 significantly reduces the number of lakes with values for mean current (1974-1983) summer surface pH.

It is interesting to observe whether relaxation of these restrictions would measurably affect our estimates of numbers or percentages of acidic lakes. First, examination of Figure 12 suggests that the error associated with 1979 pH measurements is fairly consistent and independent of the true pH. Thus a correction factor for 1979 data, equivalent to the average deviation between the estimate of current pH (excluding 1979 data) and the 1979 data (0.70 ± 0.09 pH units) could be derived. The distribution of the recalculated mean current summer surface pH, including corrected 1979 electrometric pH measurements, is illustrated in Figure 22. Sample size has increased from 693 lakes to 1003 lakes. The percentage of lakes with pH <5.0 has dropped from 24.7% in the original figure (Figure 13) to 18.6%. The percentage of lake surface area with pH <5.0 drops from 4.2% (Figure 14) to 2.9%. It is not clear to what degree the magnitude of change in these percentages reflects the magnitude of the correction factor (+0.70) applied to 1979 data rather than a true decrease in the proportion of acidic lakes with increasing sample size. Regional extrapolations from this sample of 1003 lakes to the 2759 Adirondack lakes would have to incorporate the error associated with the corrected 1979 data, and have not been pursued. In a similar manner, estimating current pH using all measurements of pH, independent of method and time of year, but still at 0-1 m depth and excluding 1979 electrometric pH data, would increase the sample size from 693 lakes to 859 lakes. In this case, the percent of acidic lakes in the sample changes little, decreasing from 24.7% to 22.3% (Figure 23); or on a lake area basis from 4.2% to 4.1%.

2.4. Summary

Although there are uncertainties concerning the representativeness of our sample and potential biases associated with within-lake variance in pH that cannot be fully resolved at this time, our best estimates of the percentage of lakes with pH <5.0 in the Adirondack Ecological Zone range between 17 and 28% (95% confidence interval; mean 22%), or about 500 to 800

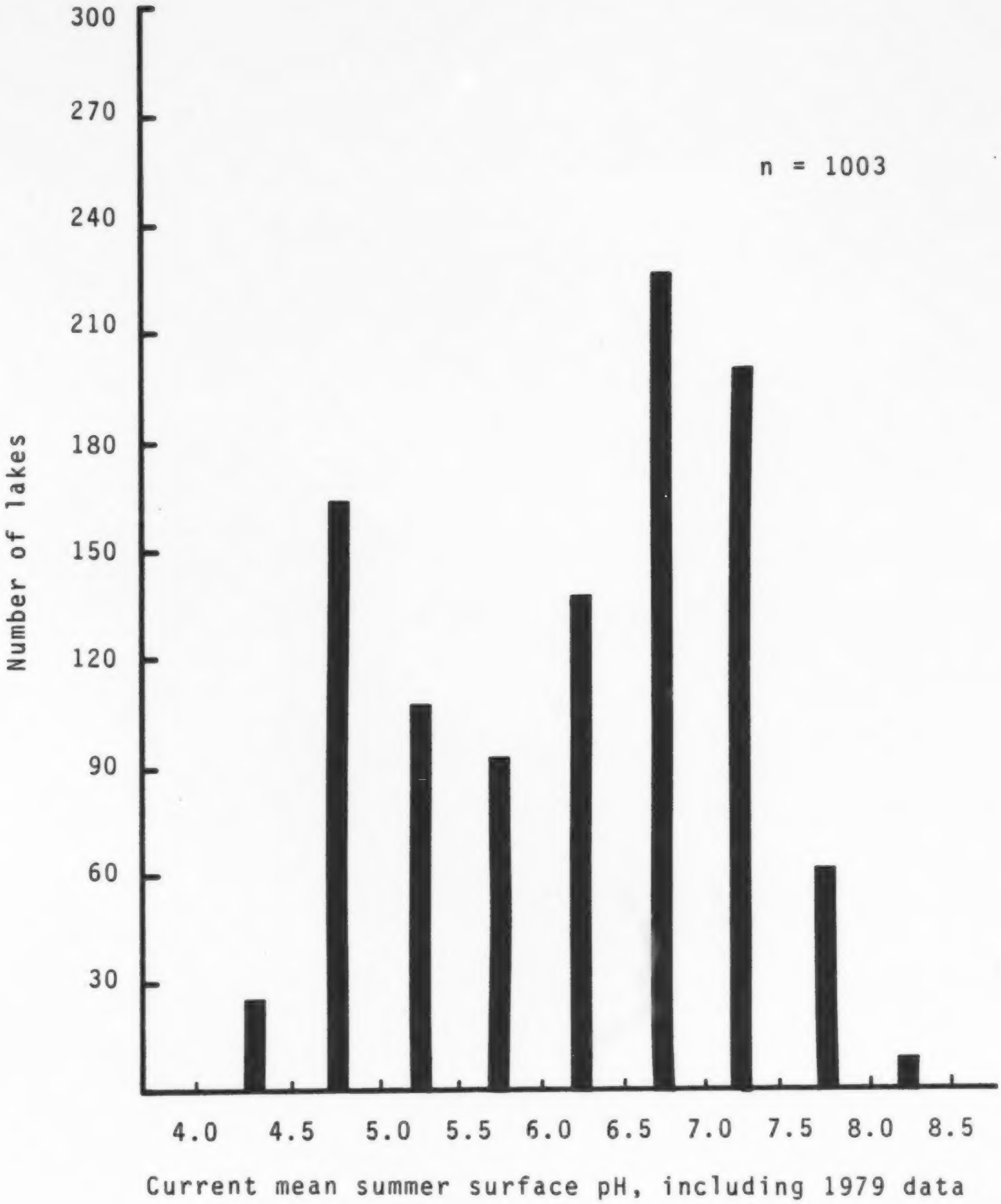

Figure 22. Frequency distribution of mean current (1974-1983) summer surface pH, including 1979 pH measurements adjusted for potential bias. All measurements electrometric, air-equilibrated.

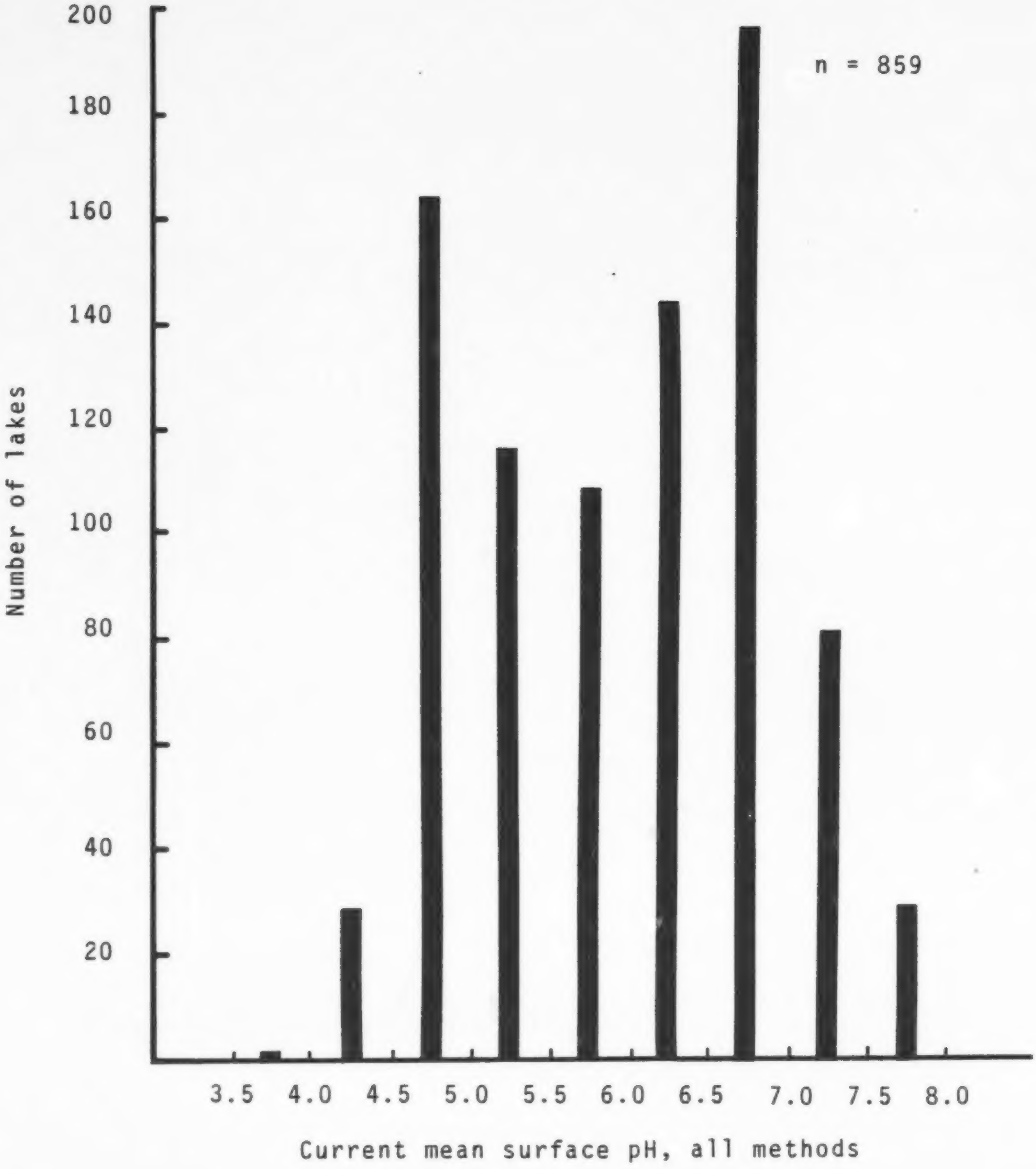

Figure 23. Frequency distribution of current (1974-1983) mean surface pH. All pH measurements and methods included, excluding 1979 electrometric pH values.

lakes. There are 693 lakes for which we have one or more laboratory electrometric, air-equilibrated measurements of pH 1974-1983 (excluding 1979) at 0-1 m depth during the summer period 1 May to 30 September. Of these 693 lakes, 171 (24.7%) have pH <5.0.

3. IS THERE A SIGNIFICANT POSITIVE CORRELATION BETWEEN ACIDITY STATUS AND CONCENTRATIONS OF DISSOLVED ORGANICS?

It is possible that the large number of low pH lakes in the Adirondacks results from natural acidification processes rather than acidic deposition. The presence of high concentrations of organic acids in lakes is indicative of one type of natural acidification process, commonly associated with the occurrence of naturally acidic wetlands and/or soils within the watershed. If natural acidification attributable to organic acids is the major factor controlling the acidity of Adirondack lakes, then lake acidity status should be positively correlated with concentrations of organic acids. We can therefore propose the following null hypothesis:

H_0: In Adirondack lakes there is no significant correlation between pH and concentration of organic acids.

If natural acidification attributable to organic acids is the major factor controlling the acidity of Adirondack lakes, we expect to reject the null hypothesis in favor of the alternative hypothesis:

H_1: Low pH levels in Adirondack lakes are associated with high concentrations of organic acids.

On the other hand, if we reject the null hypothesis in favor of a second alternative hypothesis:

H_2: Low pH levels in Adirondack lakes are associated with low concentrations of organic acids,

then acidification may be attributed to factors other than organic acids, perhaps acidic deposition. There are, however, other natural acidification processes that do not involve organic acids. Thus no correlation between pH and organic content, or a negative correlation between acidity status and organic content, is not sufficient proof that acidic deposition is a major factor controlling the acidity of Adirondack lakes. The hypothesis that acidic deposition has resulted in significant acidification of surface waters in the Adirondacks unfortunately cannot be rigorously tested based solely on survey data and correlations.

We would like to evaluate the above hypotheses concerning the relationship between lake acidity and organic acids using the FIN data base. Unfortunately, relatively few lakes within the Adirondacks have measurements of organic acidity, or even dissolved organic carbon (DOC). No data on organic acids or DOC are available in FIN. Thus at best we can test these hypotheses using an indicator of organic content, visual water color, as described in section 1 above. To accommodate the use of this indicator of organic content, rather than actual measurements of organic acidity, the hypotheses to be tested must be revised. Two null hypotheses are proposed:

> H_o: Current pH levels in lakes low in organic content (clear-water lakes, visual color <1.5) are not significantly different from current pH levels in lakes with high concentrations of dissolved organics (lakes colored light brown or brown, visual color >2.5).

and

> H_o: The proportion of lakes (in a given pH range) classified as highly colored (visual color >2.5) is not significantly correlated with lake pH.

Again, if organic acids play a major role in controlling the acidity of Adirondack lakes we expect to reject these null hypotheses in favor of the alternative hypotheses:

> H_1: Current pH levels in highly colored lakes (visual color >2.5) are significantly lower than current pH levels in clear-water (visual color <1.5) Adirondack lakes.

and

> H_1: The proportion of lakes classified as highly colored (visual color >2.5) increases with decreasing lake pH.

If the null hypotheses are not rejected or are rejected such that clear-water lakes are more acidic and the proportion of lakes classified as highly colored decreases with decreasing pH, then organic acids are not *the* major factor controlling lake acidity. Organic acids, however, may still be one of a number of factors contributing to lake acidity.

Visual color observations (since 1960) and current pH data (mean summer surface electrometric pH measurements, 1974-1983 excluding 1979) are available for 305 lakes in the Adirondack Ecological Zone. Ninety-three percent of these were classified as either clear water (visual color <1.5) or colored light brown or brown (visual color >2.5). The remainder had mean values for visual color between 1.5 and 2.5. Using both parametric (t-test) and non-parametric (Wilcoxon score) procedures, current pH levels in clear-water lakes are significantly (p <0.01) lower than current pH levels in lakes classified as light brown or brown (Figure 24). Likewise, the proportion of lakes classified as highly colored decreases significantly (p <0.01) with decreasing pH (Snedecor and Cochran, 1976, for linear trend in proportions) (Figure 25).

Thus the data do not support the contention that the presence of organic acids is the major factor controlling lake acidity. In general, lakes with pH ≥5.0 are more likely to be highly colored (58%) than are lakes with pH <5.0 (43%). A small number of lakes (n=15), however, had quite low pH (4.0-4.5), and tended to be highly colored (80% with visual

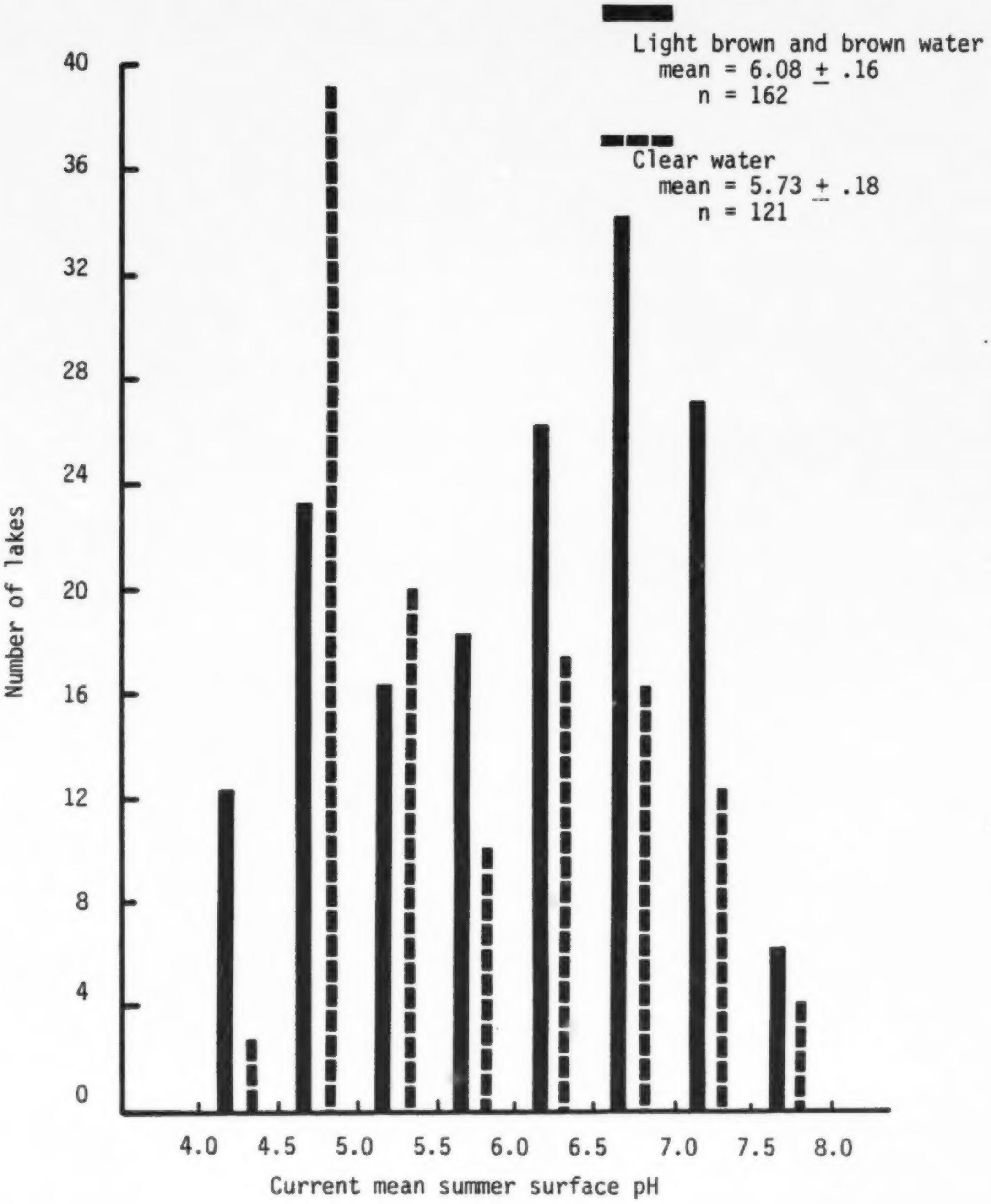

Figure 24. Frequency distribution of current (1974-1983) mean summer surface pH for clear-water lakes (visual color <1.5) and lakes classified as light brown or brown water (visual color >2.5).

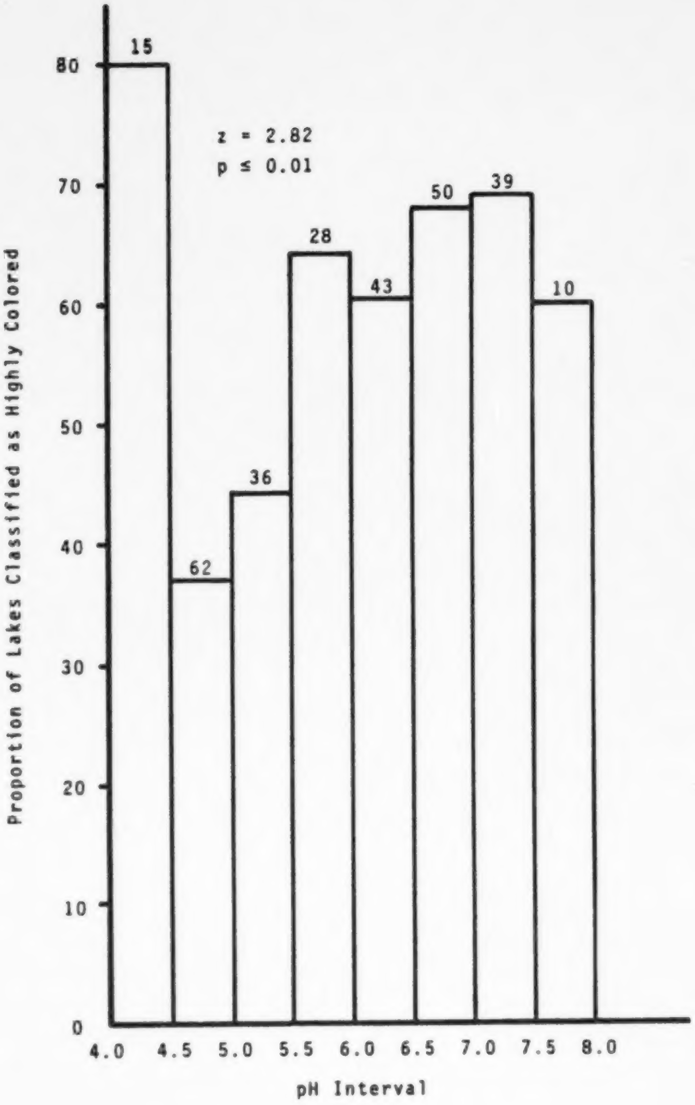

Figure 25. Proportion of lakes classified as highly colored, light brown or brown (visual color >2.5) in 0.5 pH intervals, pH 4.0 to 8.0. The proportion of lakes classified as highly colored is based upon the sum of lakes classified either as highly colored or as clear-water lakes (visual color <1.5). Number of lakes in pH interval noted.

color > 2.5). These lakes likely represent the small bog ponds common in certain parts of the Adirondacks.

4. WHAT PROPORTION OF ACIDIC LAKES HAVE HIGH CONCENTRATIONS OF DISSOLVED ORGANICS?

Dystrophic lakes, or lakes with high concentrations of dissolved organics, are common in the Adirondacks. The presence of high concentrations of dissolved organics is of interest for three reasons: (1) the relative contribution of organic acidity to the total acidity, and the possibility that the lake is naturally acidic, (2) the contribution of organic acids to the buffering capacity, potentially decreasing the sensitivity of the lake to acidic deposition, and (3) complexation of aluminum with organics thereby reducing toxic effects on fish. FIN contains no measures of dissolved organic concentration. Thus at best we can determine the proportion of acidic lakes (pH <5.0) that were classified as colored light brown or brown (visual color >2.5).

In our sample of 305 lakes with both current pH data and visual color observations, 82 lakes had pH <5.0. Of these 82 lakes, 35 lakes (43%) were classified as colored light brown or brown (visual color >2.5), 42 lakes (51%) were classified as clear water (visual color <1.5), and 5 (6%) had indeterminate visual color readings between 1.5 and 2.5.

Is this sample of 82 acidic lakes representative of acidic Adirondack lakes in general? Again we are only able to examine representativeness with regard to lake size and elevation. From Figures 26-28 it apears that lakes with pH <5 are somewhat more likely to be highly colored if they are very small (<5 ha) and occur at higher elevations. Relative to the 171 lakes in FIN with current pH <5.0 (Figure 13), the sample of 82 lakes with pH <5.0 for which we also have observations of visual color spans similar ranges of elevation and area (Figures 29 and 30). Thus the percentage of highly colored waters in the 82 lakes (43%) may approximate the percentage of highly colored waters in the 171 acidic lakes. Extrapolation to all acidic Adirondack lakes is difficult, but calculations in section 2 above suggest that a major change in the estimated proportion of highly color waters is unlikely. Thus it appears that a high percentage, perhaps 40-50%, of the Adirondack lakes with pH <5.0 are highly colored, light brown to brown, indicative of fairly high concentrations of dissolved organics.

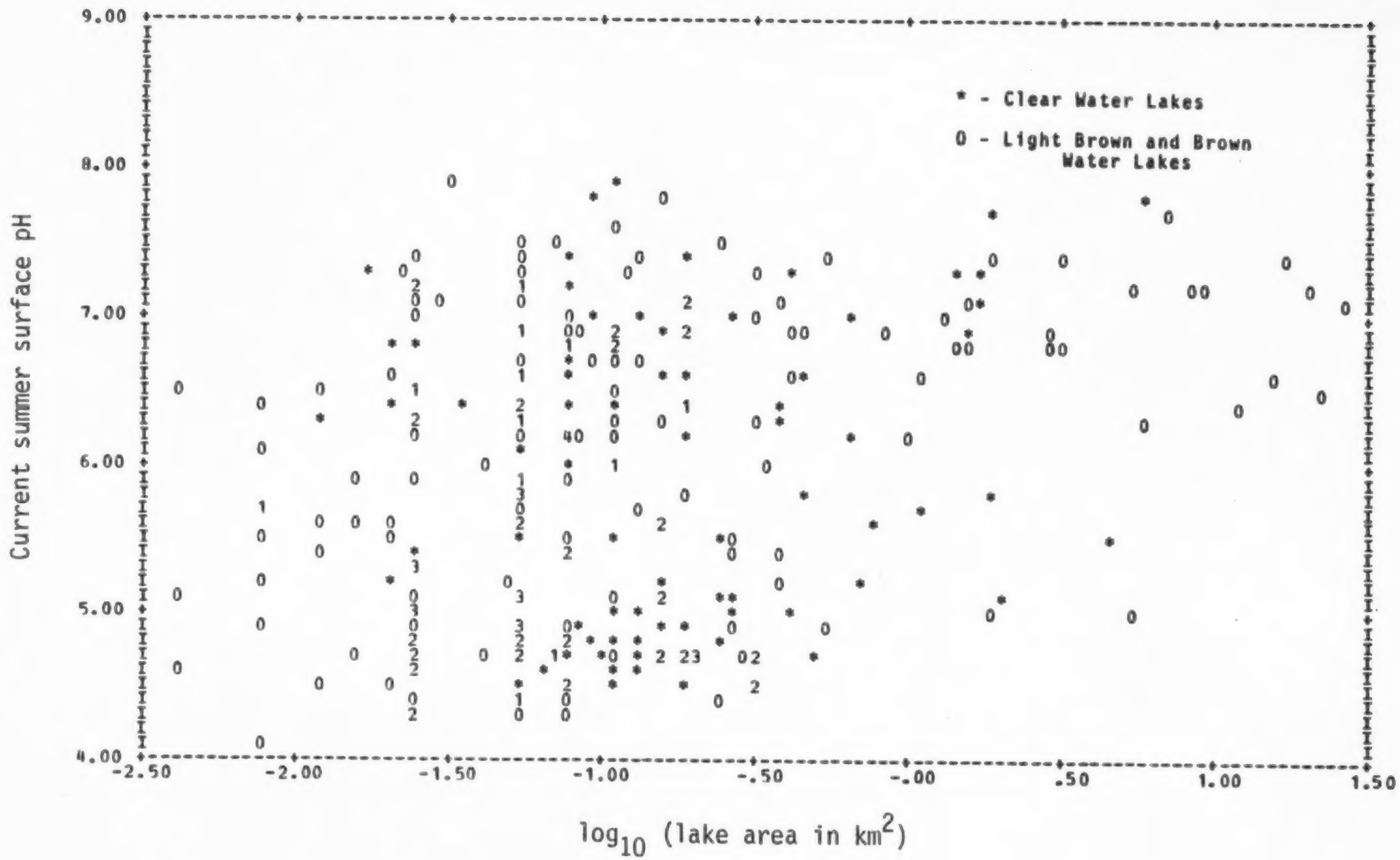

Figure 26. Distribution of clear-water lakes (visual color <1.5) and lakes classified as light brown or brown (visual color >2.5) by current (1974-1983) summer surface pH and $\log_{10}$ (lake area in km^2).

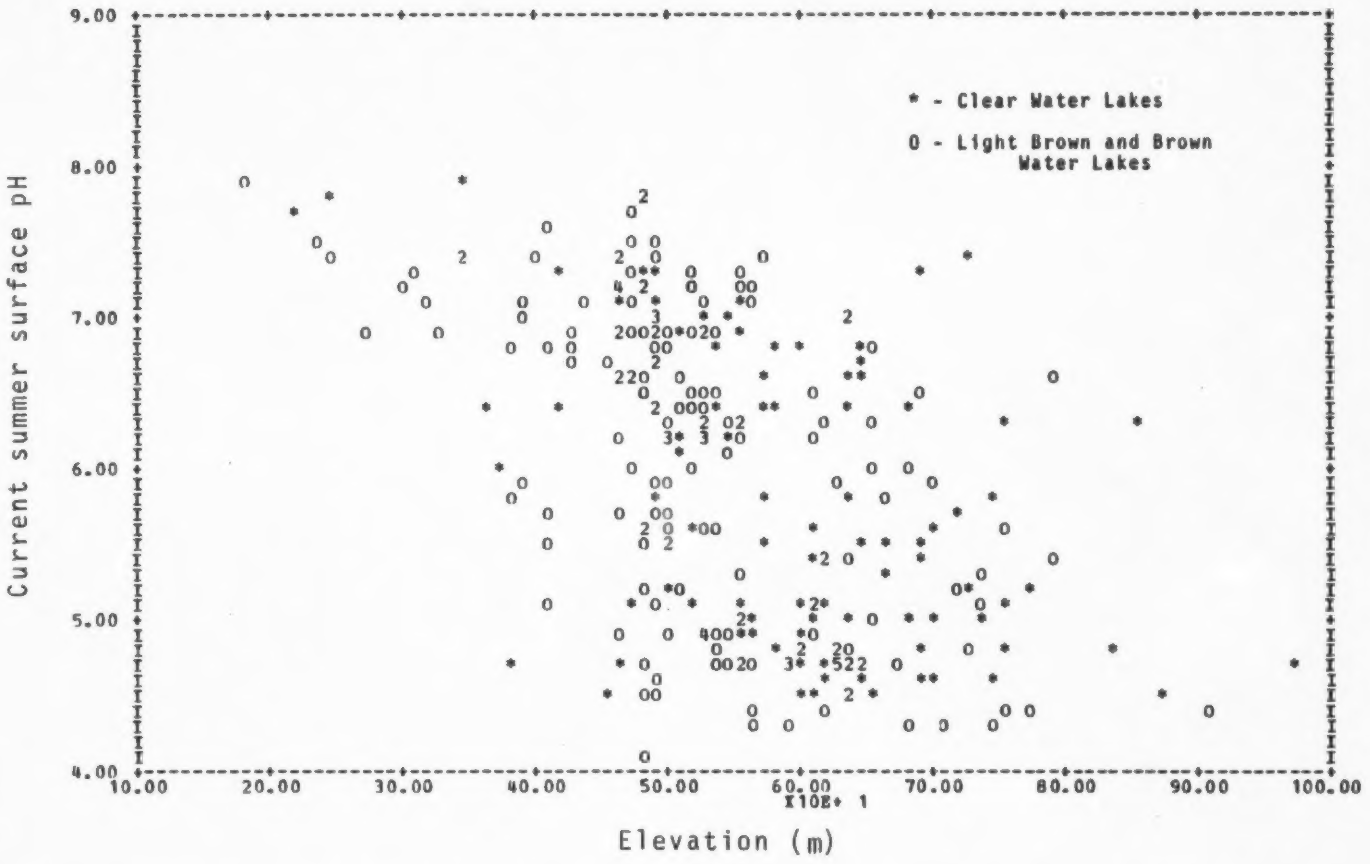

Figure 27. Distribution of clear-water lakes (visual color <1.5) and lakes classified as light brown or brown (visual color >2.5) by current (1974-1983) summer surface pH and lake elevation (m).

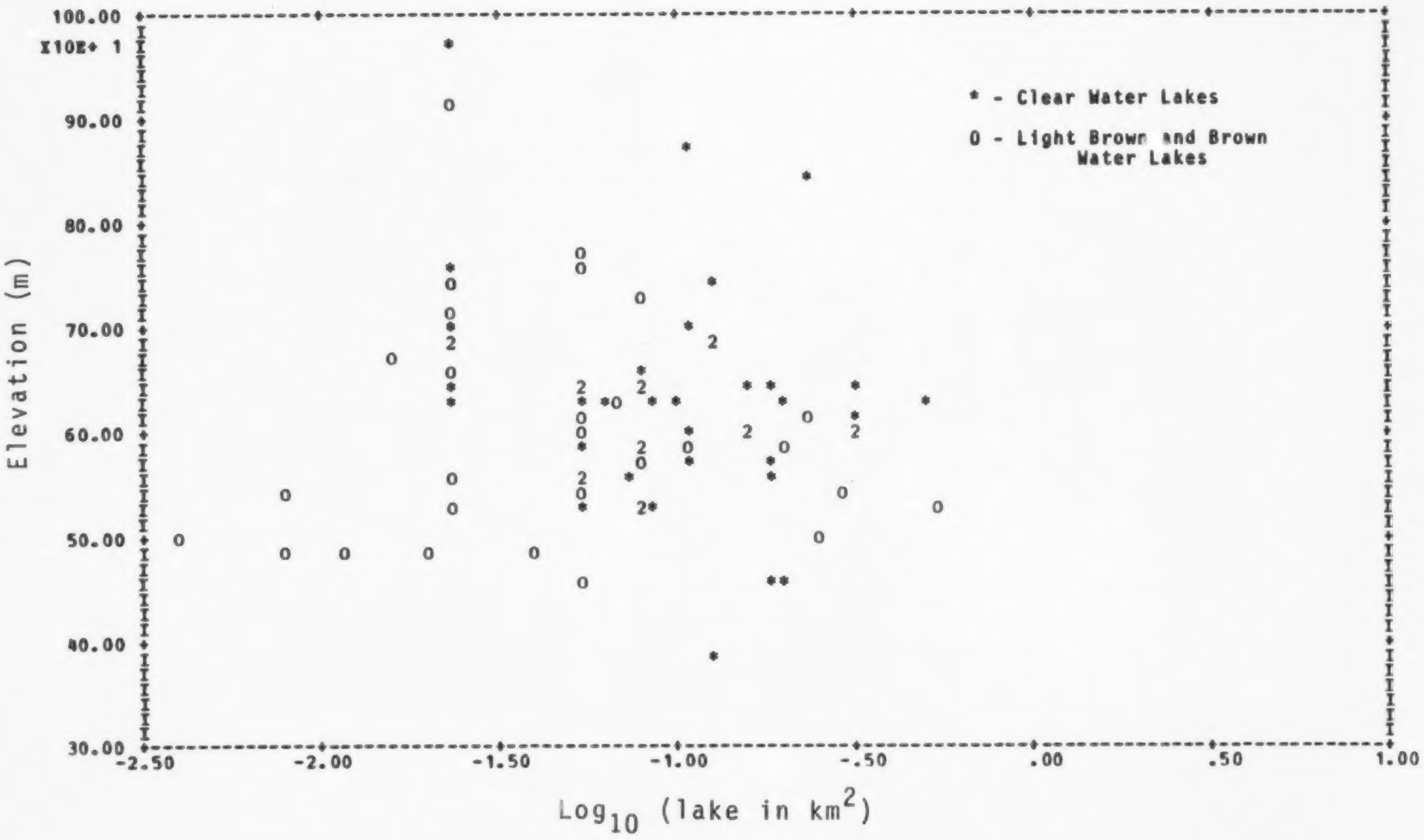

Figure 28. Distribution of clear-water lakes (visual color <1.5) and lakes classified as light brown or brown (visual color >2.5) with pH <5.0 by elevation (m) and $\log_{10}$ (lake area in km^2).

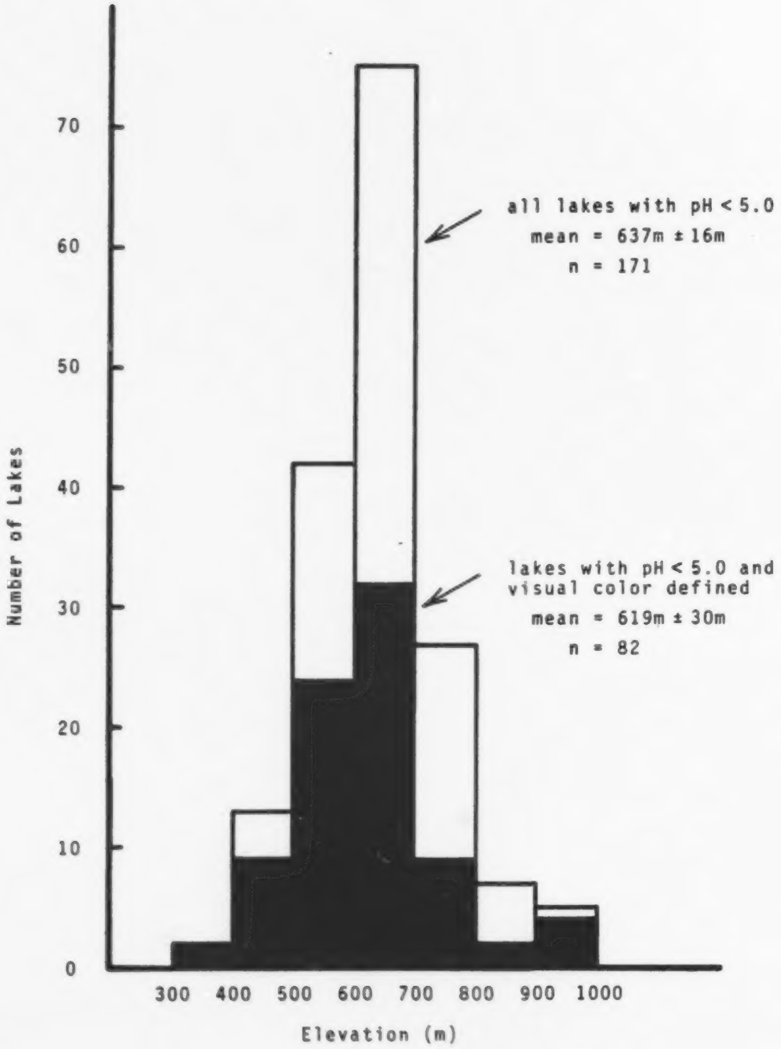

Figure 29. Frequency distribution of elevation (m) for lakes with pH <5.0.

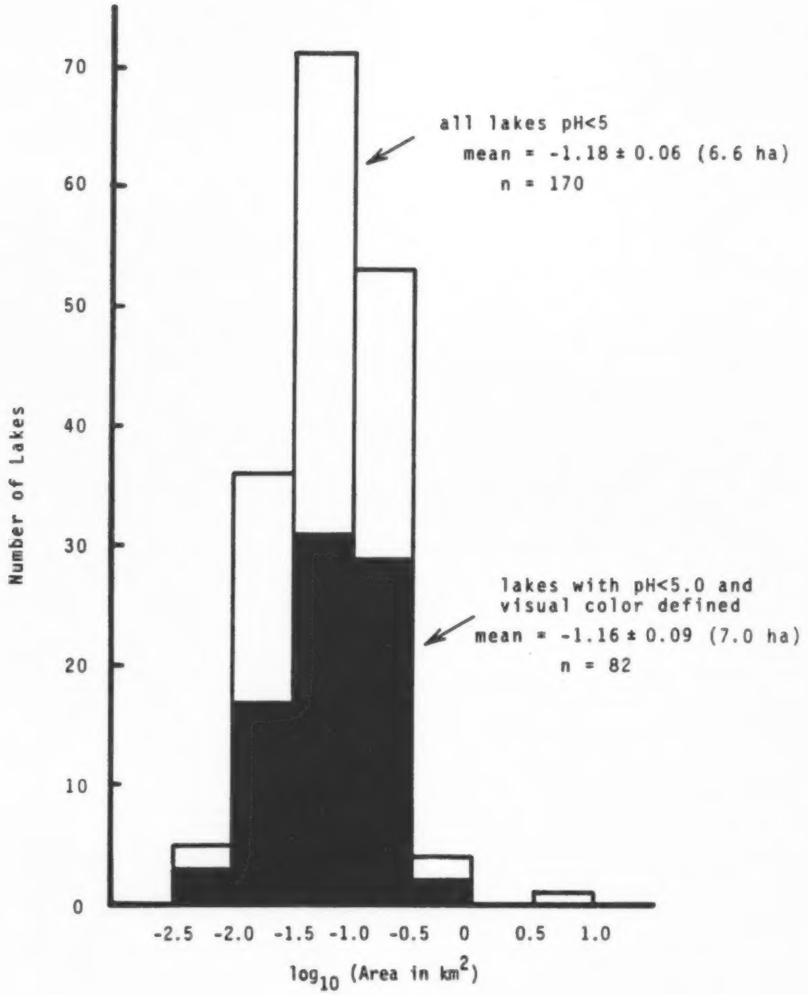

Figure 30. Frequency distribution of Log_{10} (area, in km^2) for lakes with pH <5.0.

5. IS THERE EVIDENCE THAT pH LEVELS IN ADIRONDACK LAKES HAVE DECREASED OVER TIME?

Although a substantial number of lakes in the Adirondacks are acidic (pH <5.0), it is possible that many of these acidic lakes have always been acidic, as a result of natural processes. We are interested in determining whether pH levels in Adirondack lakes have decreased over time. What fraction of the lakes currently acidic have experienced significant declines in pH within the last 20-50 years?

Evaluations of changes in pH level over time are unfortunately severely hampered by the quality and quantity of historical pH data available. Problems associated with comparison of historical and current pH (or alkalinity) data have been reviewed by Church (1984), and will not be repeated here. Hendrey et al. (1984) proposed one approach for analysis of temporal trends that is particularly appropriate for assessing regional patterns. Rather than relying on detailed analyses of changes in water chemistry over time at one or a few sites, Hendrey et al. (1984) compiled all available water quality at all available sites within defined regions, analyzed for trends over time at each station, and then aggregated these results for a regional assessment. Changes in chemical variables over time were evaluated based on a simple linear regression model. Further justification for the use of the simple linear model and discussion of the limitations of this approach are provided by Hendrey et al. (1984). Temporal trends in pH for the Adirondacks, using the data in FIN, have been analyzed in a similar manner.

For each lake in the Adirondack Ecological Zone with sufficient data, coefficients for the linear model:

$$y_i = b_o + b_i x_i + e_i$$

were estimated, where y_i is the mean pH measured on a given day over all depths, x_i is Julian time converted to units of decades, and e_i is the random error term. All pH measurements, all methodologies, were used with the exception of 1979 electrometric pH data. Lakes were considered to have sufficient data for analysis of trends if pH data spanned a minimum of 10 years. Thus, the change in pH over time (b_1 in the above equation) was estimated for lakes with as few as two pH measurements separated by at least 10 years. Obviously, the statistical significance of these trends, based on two data points, could not be evaluated. The likelihood of detecting significant trends increases as the number of pH observations increases. Examination of trends in a sample of lakes (with n = 3 to 27) suggested that the linear approximation of pH as a function of time was adequate; no better or worse than the alternative model considering H^+ concentration as a linear function of time. pH was selected for trend analysis, rather than alkalinity, because of its direct application to potential effects on fish and because of the greater uncertainty concerning the validity of comparing current and historic measurements of alkalinity.

Of the 2759 lakes in the Adirondack Ecological Zone, 650 have sufficient data for estimation of the rate of change in pH over time; 246

lakes (38%) have only two pH observations, 152 lakes (23%) have 5 or more pH measurements (Figure 31). Data for all 650 lakes spanned $\geq$ 10 years; 475 lakes (73%) had pH observations spanning $\geq$ 20 years (Figure 32). In most cases (84%) the most recent pH measurement is post-1970.

The estimated rate of change in pH over time can be used to examine several hypotheses. First, if acidic deposition is the major factor controlling the acidity of Adirondack lakes, and if acidic deposition has increased over the last 10-50 years, then pH levels in lakes in the region as a whole should have decreased over time. Thus the null hypothesis:

> H_0: For Adirondacks lakes overall, pH has not changed over time, i.e., the regional trend coefficient ($\bar{b}_1$) is not significantly different from zero.

should be rejected, and the alternative hypothesis:

> H_1: the regional trend coefficient ($\bar{b}_1$) is significantly less than zero.

should be accepted.

For the 650 lakes with sufficient data, the estimated rate of change in pH (b_1) ranged from -1.27 to +1.12 pH units per 10 years, with an average of +0.008 ± 0.021 pH units per decade (Figure 33). Restricting the analysis to lakes with 5 or more pH observations over $\geq$ 10 years, the regional trend coefficient (b_1) increases to 0.071 ± .048 pH units per 10 years. Twenty-six lakes (4%) had statistically significant ($p \leq 0.05$) decreases in pH over time, 27 (4%) had significant increases in pH over time, and 597 lakes (92%) had no significant trend in pH. The "significance" of trend coefficients for individual lakes must, however, be interpreted with caution. We would expect that 5% of the 650 lakes would be classified as having significant trends solely as a result of random error. The regional trend coefficient is therefore not significantly different from zero and the null hypothesis of no regional trend in pH over time is not rejected.

There are several possibilities why no regional trend in pH is evident: (a) acidic deposition in the Adirondacks has not increased over the past 10-50 years, (b) acidic deposition has no effect on lake pH, (c) acidic deposition is only one of a number of factors controlling acidity levels in Adirondack lakes, or (d) problems with data quantity and/or quality limit our ability to detect temporal trends. Hendrey et al. (1984), in a similar analysis based on data for New England and New York in ACID (Acidification Chemistry Information Database), observed a significant regional decrease in sulfate, significant increase in alkalinity, and no significant change in H^+ concentration over time. They attributed these trends (or lack of trend) to decreases in sulfur emissions in the region since 1967-1970 (and thus presumably decreases in acidic deposition over the last 10-15 years). A similar explanation may be appropriate for the Adirondacks but confirmation would require a more detailed analysis of temporal pH (and other water quality) trends. While the majority of data analyzed by Hendrey et al. (1984) spanned only from the 1960's to the

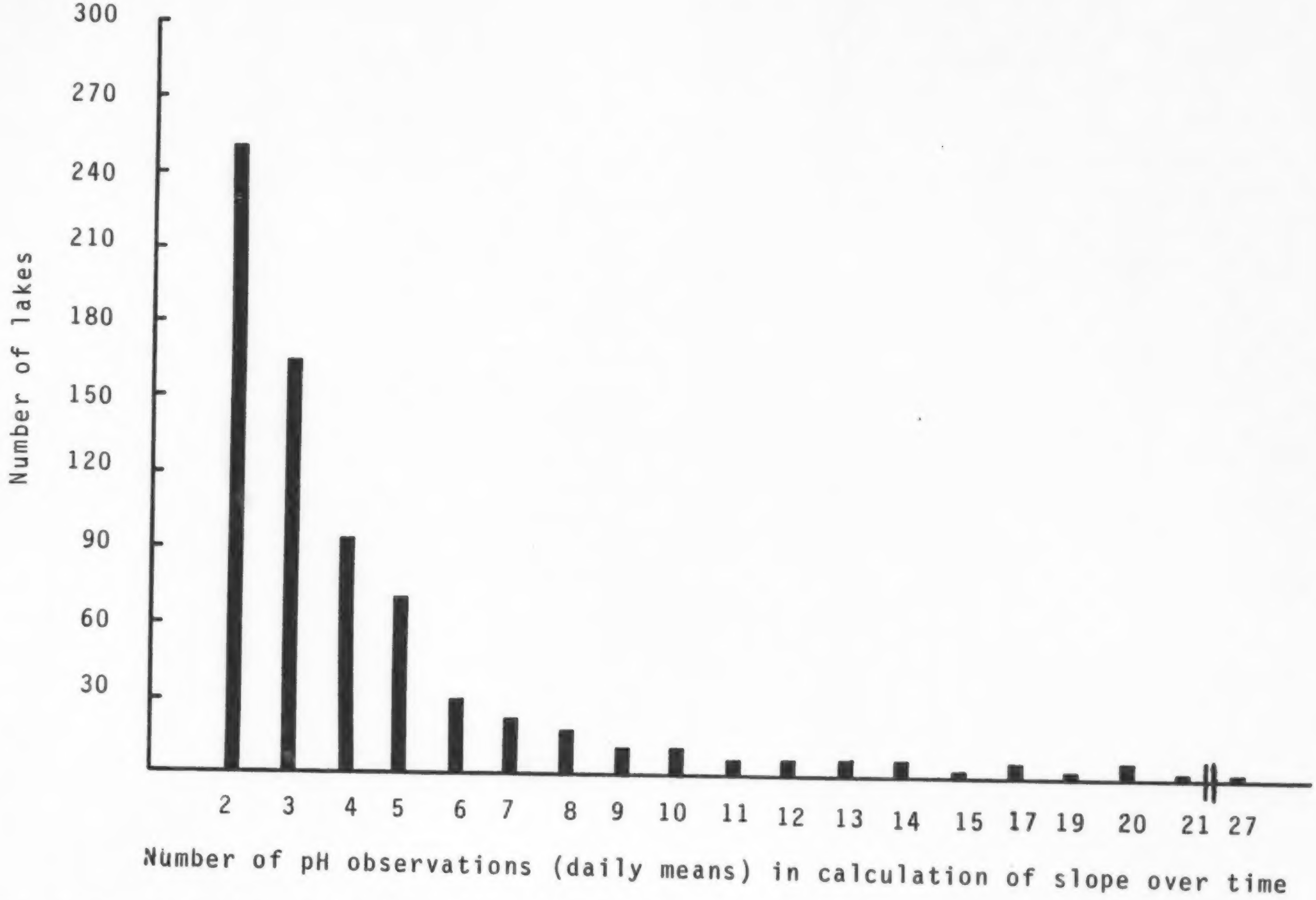

Figure 31. Frequency distribution of number of pH observations (daily means) used in the calculation of slope (change in pH over time).

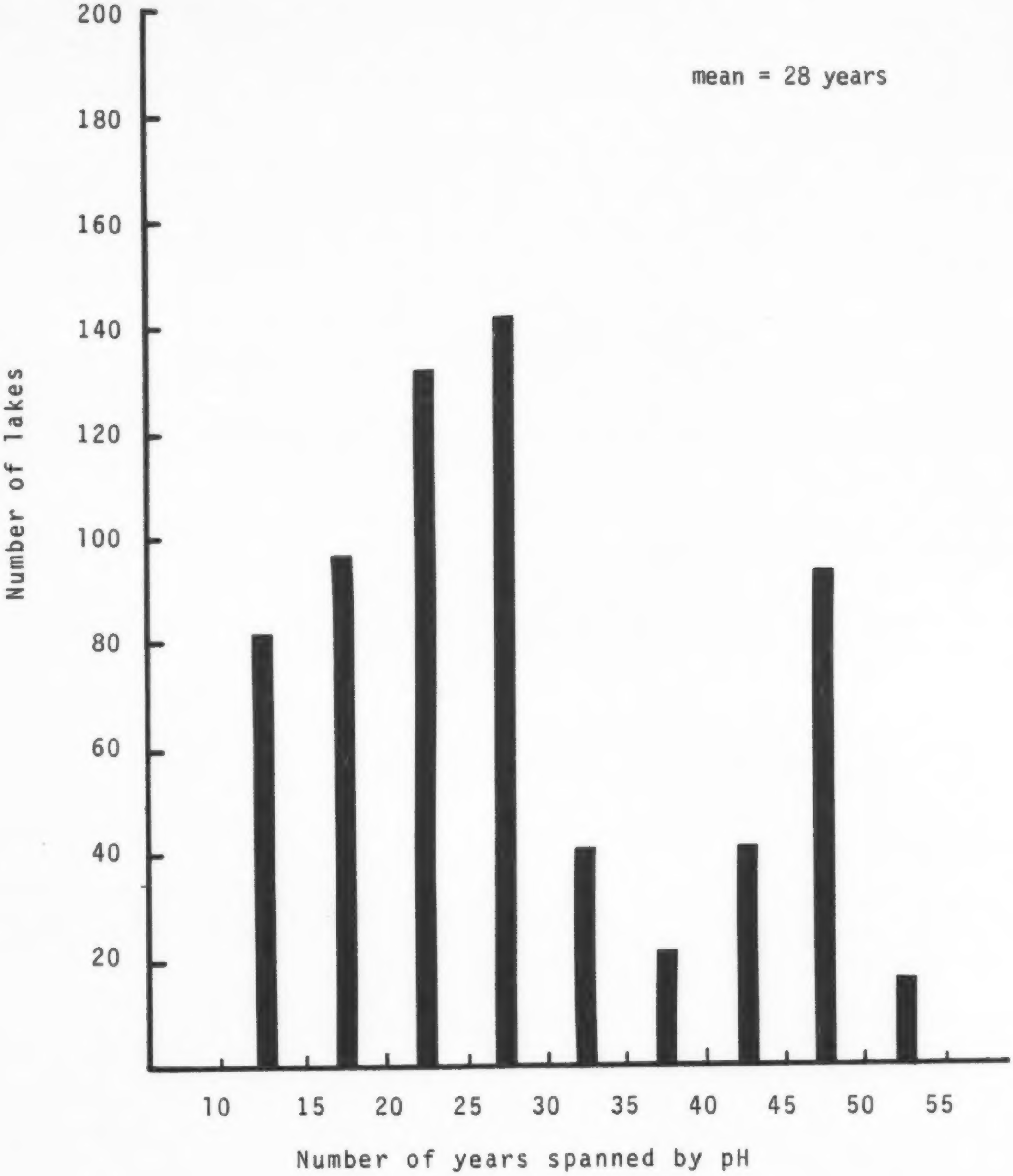

Figure 32. Frequency distribution of number of years over which pH data span for calculation of slope (change in pH over time).

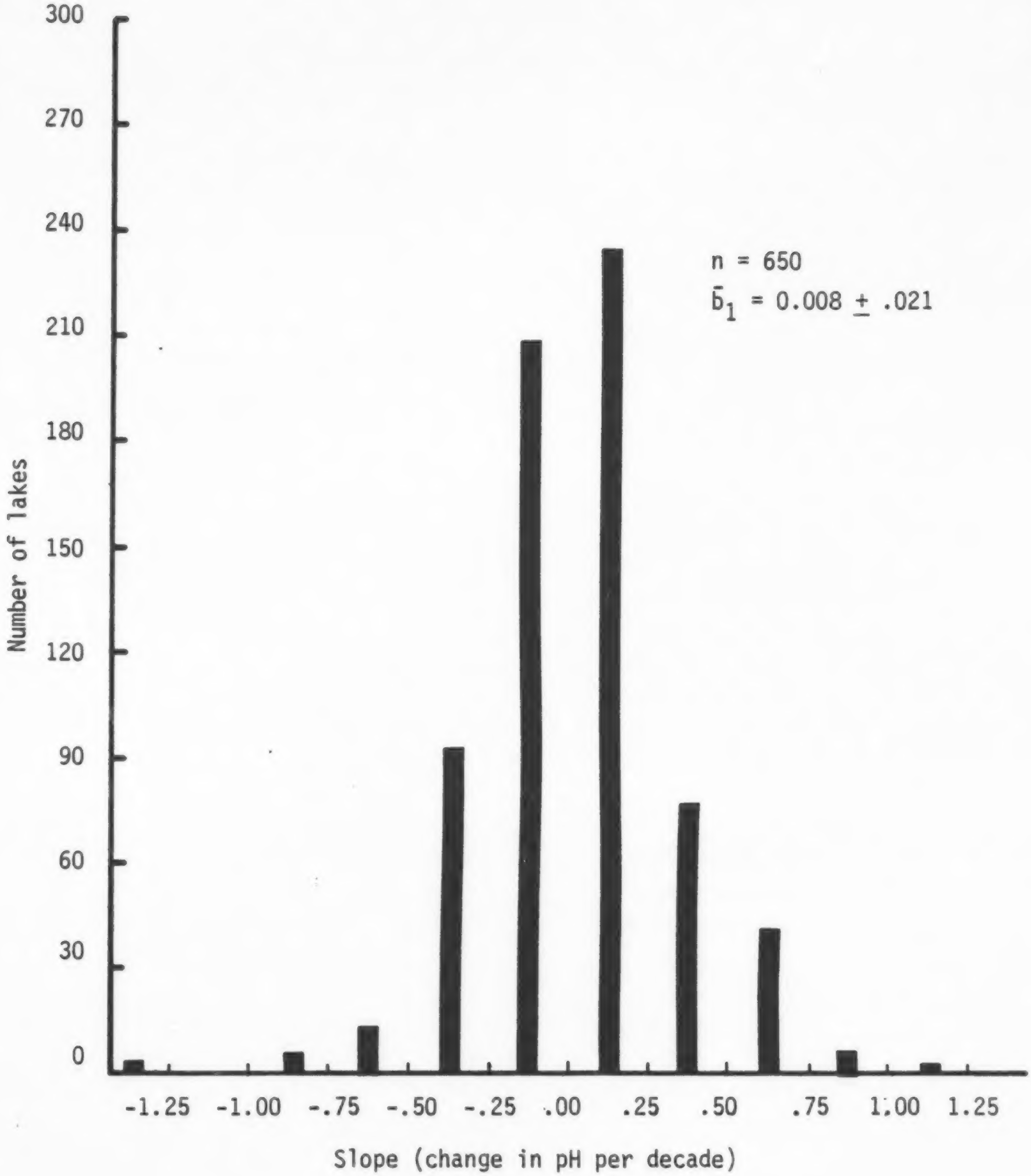

Figure 33. Frequency distribution of slopes (change in pH over time).

present, 35% of the trend analyses from FIN date back to pre-1940, and 80% to pre-1960. A preliminary examination of pH data for individual lakes suggests no pattern of decreasing pH followed by an increase in pH since 1967-1970. Few lakes, however, have sufficient data for a detailed analysis of temporal trends.

Acidic deposition may also be one of a number of factors controlling acidity levels in Adirondack lakes, and changes in pH through time. For example, cultural eutrophication associated with expanding populations and recreational activities may act to increase pH in some lakes, particularly the larger lakes at lower elevations that have been more heavily developed. In this case, the probability of detecting temporal trends related to acidic deposition would be increased by focusing analyses on lakes most likely to have been impacted.

For a variety of reasons (reviewed by Dillon and Galloway 1984), small headwater lakes located at higher elevations are particularly sensitive to acidic deposition. At higher elevations, watershed to lake area ratios tend to decrease and soils are generally thinner. Both of these factors contribute to increasing sensitivity to acidic inputs. We would expect, therefore, that with increasing elevation a greater proportion of lakes would exhibit decreases in pH over time, and that the null hypothesis:

> H_0: The regional trend coefficient ($\bar{b}_1$) for high elevation (> 610 m) Adirondack lakes is not significantly different from zero

would be rejected in favor of the alternative hypothesis:

> H_1: The regional trend coefficient ($\bar{b}_1$) for high elevation Adirondack lakes is significantly less than zero.

The regression of slope (pH over time) as a function of elevation is significant ($p \leq 0.01$) and negative (Figure 34). The relationship is even clearer if only lakes with statistically significant ($p \leq 0.05$) slopes, positive or negative, are considered (Figure 35). For the 130 lakes at elevation ≥ 610 m with sufficient data, the estimated rate of change in pH (b_1) ranged from -1.27 to 0.63 pH units per decade, with an average of -0.12 ± .05 pH units per decade. Thus, for this select group of lakes, the null hypothesis is rejected. The regional trend coefficient ($\bar{b}_1$) is significantly ($p \leq 0.05$) less than zero indicating an overall decline in pH over time in high elevation lakes.

In a similar manner, lakes that are currently acidic would be considered more likely to have been acidified. What fraction of the lakes currently acidic have experienced significant declines in pH within the last 20-50 years? Defining acidic arbitrarily as pH <5.0, 81 acidic lakes have sufficient data for analysis of trends. The estimated rate of change in pH (b_1) ranges from -1.27 to 0.28 pH units per decade, with a mean value of -0.29 ± .05 pH units per decade (Figure 36). Thus, as a group lakes currently acidic have also experienced a significant ($p \leq 0.05$) decrease in pH over time. Of the 81 acidic lakes with sufficient data, pH levels declined in 71 lakes (88%); 10 lakes (12%) experienced statistically

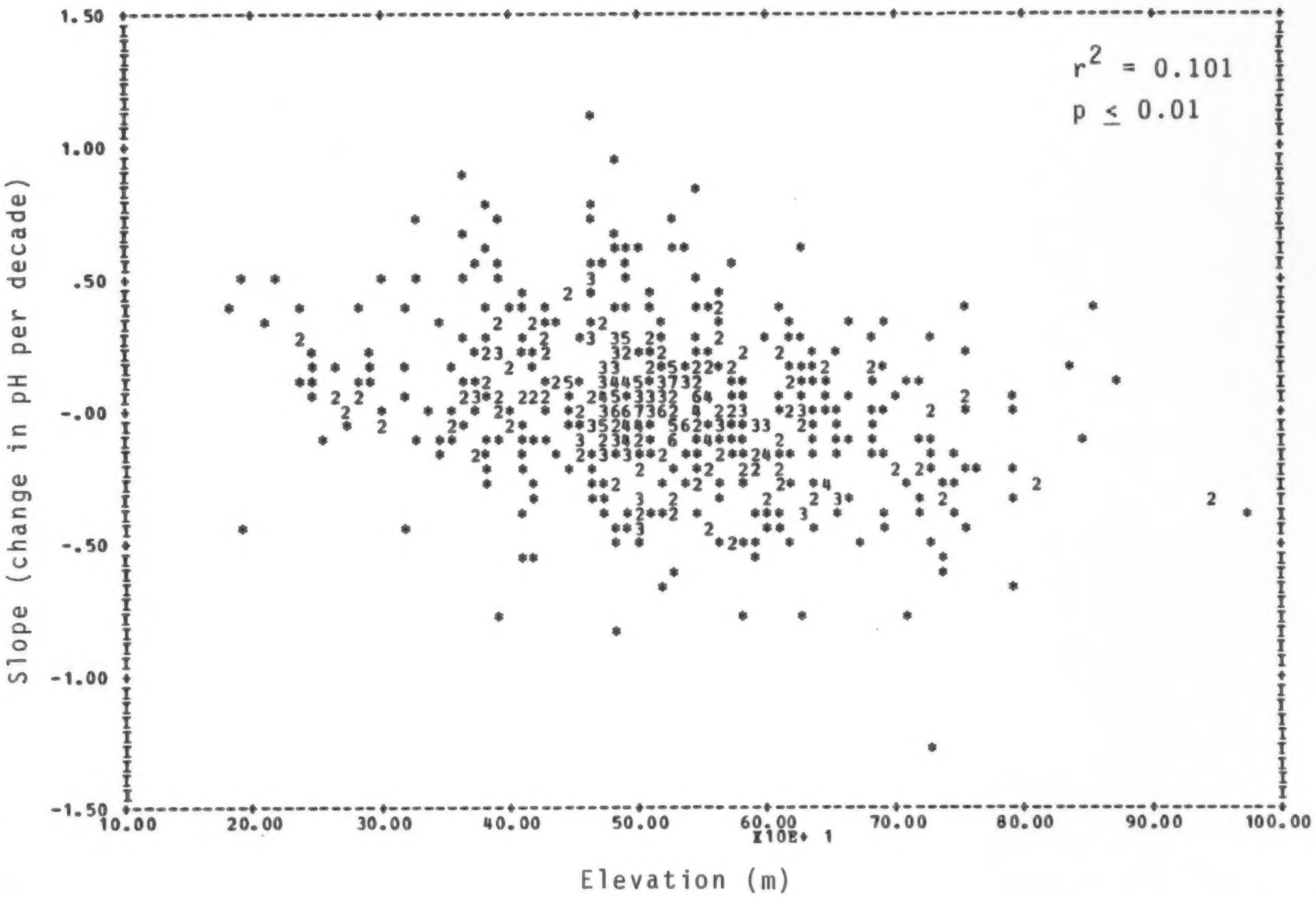

Figure 34. Slope (change in pH per decade) plotted as a function of lake elevation (m).

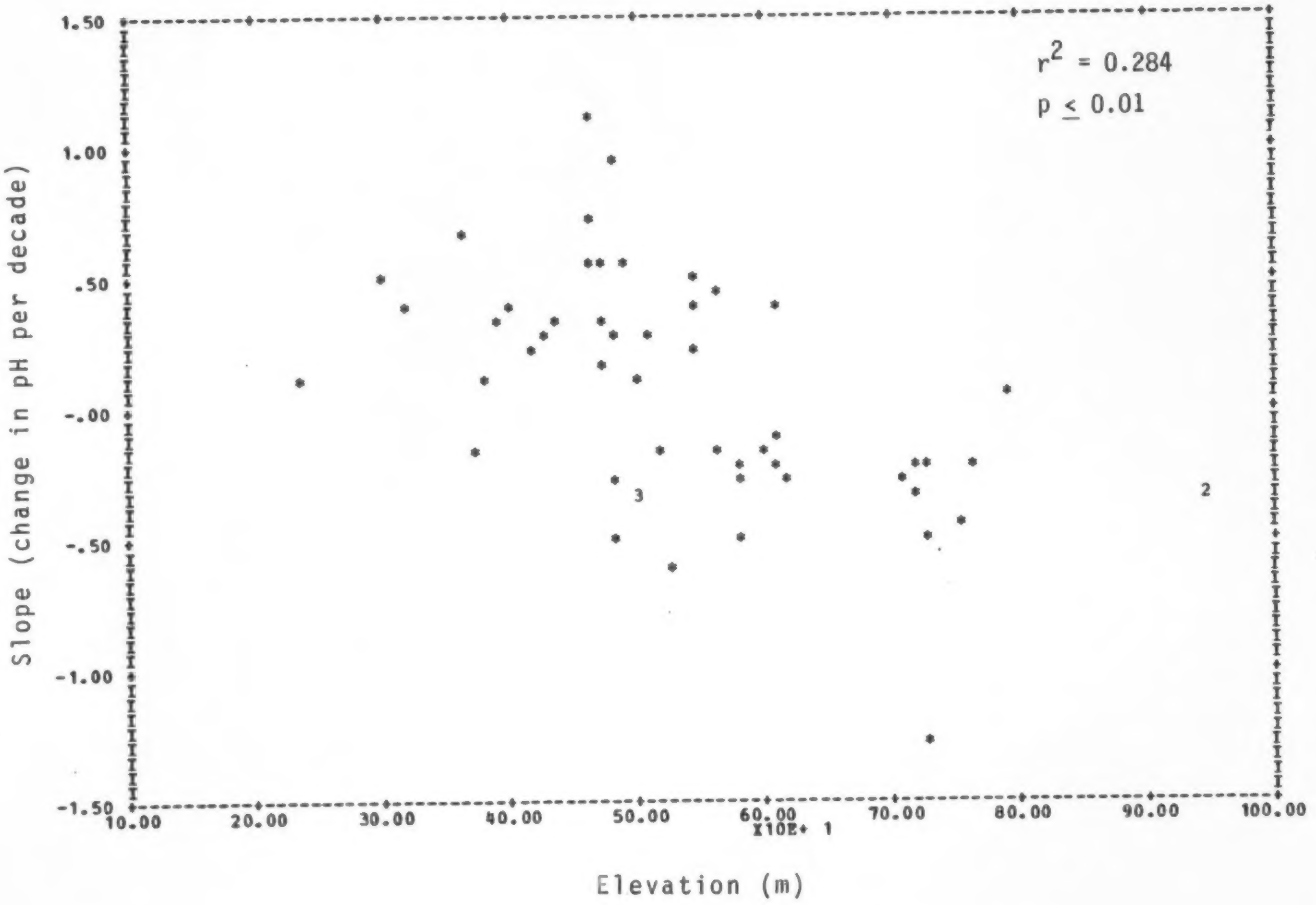

Figure 35. Slope (change in pH per decade) plotted as a function of lake elevation (m). Only slopes significant (negative or positive) at $p \leq 0.05$ are included.

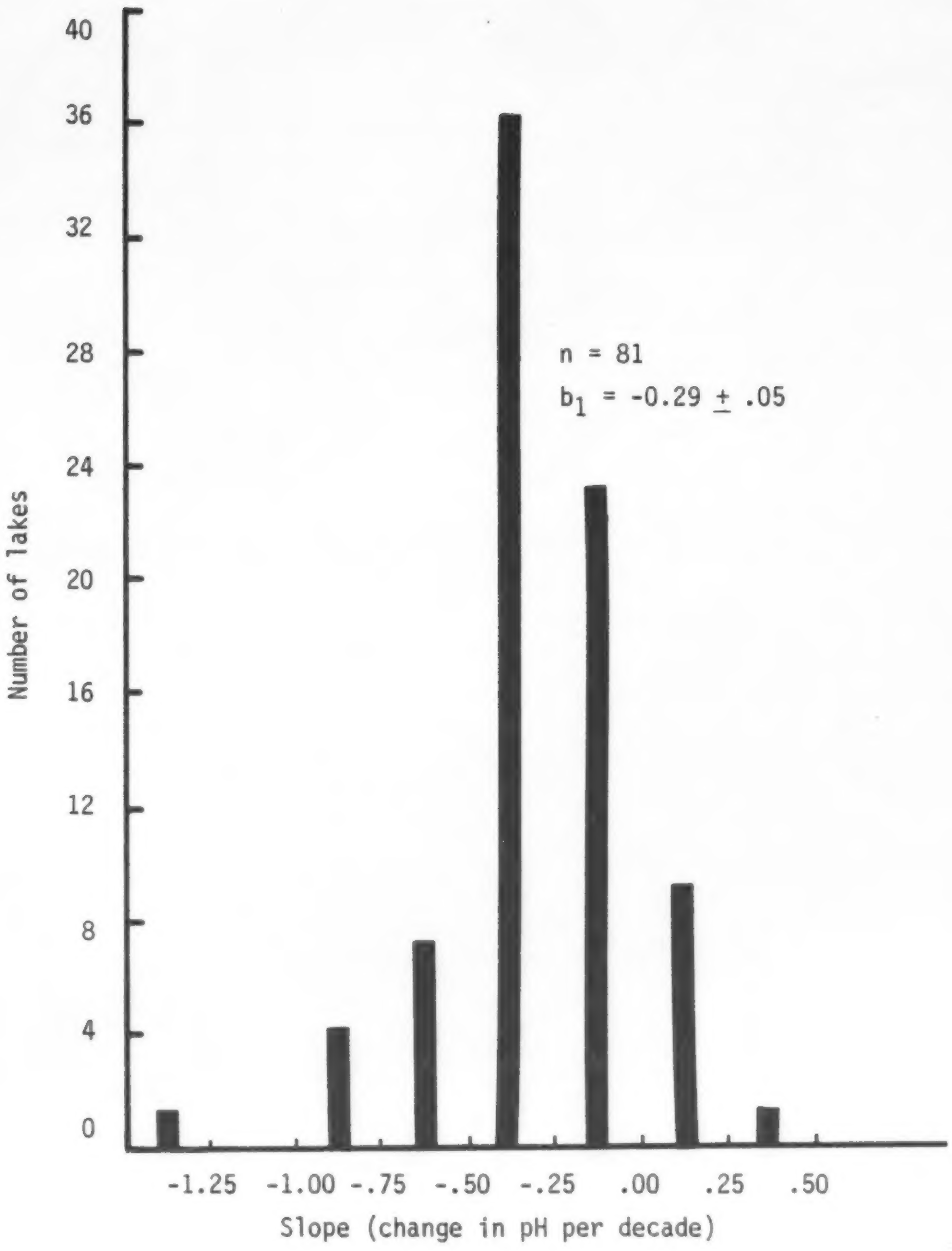

Figure 36. Frequency distribution of slope (change in pH per decade) for lakes with current summer surface pH <5.0.

($p \leq 0.05$) significant decreases in pH over time; none experienced statistically significant increases in pH.

Thus, while the evidence does not indicate that pH levels in Adirondack lakes in general have declined, pH levels appear to have declined significantly for specific subsets of Adirondack lakes, in particular lakes currently acidic (pH <5.0) and/or at high elevations ($\geq$ 610 m). Individual lakes with significant negative trends in pH over time are clearly clustered at the higher elevations and have lower pH levels currently (Figures 37 and 38). The lack of a significant trend in Adirondack lakes in general suggests several possibilities; (1) only lakes at higher elevations are sensitive to acidic deposition (2) other factors (e.g., cultural eutrophication) counterbalance effects of acidic deposition by stabilizing or increasing pH levels in some Adirondack lakes, or (3) given the limited quantity of historical data available and problems associated with data quality, trends in pH, although occurring in the majority of Adirondack lakes, can be detected only for those lakes that have experienced the most dramatic decreases in pH, i.e., lakes currently acidic and/or at high elevations.

These results should be interpreted with caution, however. Changes in methods for measurement of pH over time may influence apparent pH trends. For example, older pH readings (pre-1970) were colorimetric. It is possible that some or all of these measurements were biased toward higher pH levels, particularly in clear-water acidic lakes. Issues related to potential errors in historical pH measurements are complex, and difficult to impossible to resolve. Our primary interest in evaluation of apparent pH trends through time is as a potential indicator of effects on fish populations, discussed in Section 7.

6. HAVE CHANGES IN pH OVER TIME OCCURRED INDEPENDENTLY OF CONCENTRATIONS OF ORGANIC ACIDS?

Hemond (1980), Retzsch et al. (1982), and others have suggested that waters with high concentrations of organic acids (and thus naturally low alkalinity and low pH) are not sensitive to atmospheric inputs of acidity, since: (1) atmospheric inputs of acidity are minor relative to the total H^+ generated by natural processes, (2) the presence of high concentrations of organic acids buffers these waters against pH change, and (3) reduction reactions in the bog/wetland environs frequently associated with waters with high levels of dissolved organics neutralize all or most of the sulfuric and nitric acids in acidic deposition. If these premises hold true, then decreases in pH over time as a result of acidic deposition should have occurred principally in waters with low levels of dissolved organics. Since FIN contains no measures of dissolved organics we have first presumed that our indicators of visual color (as clear water vs. light brown or brown waters) adequately distinguish between waters with low and high concentrations of dissolved organics (this assumption has not been tested), and test the following null hypothesis:

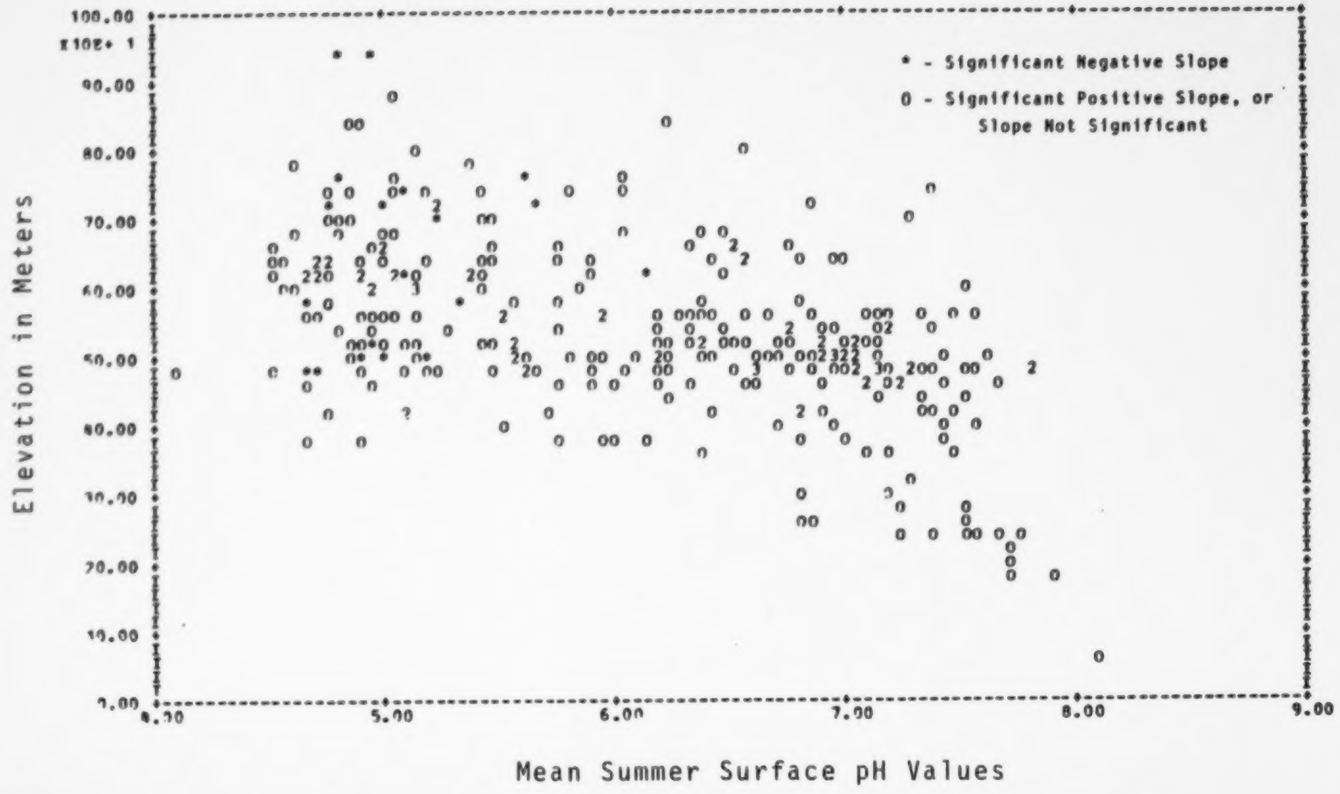

Figure 37. Distribution of lakes with significant ($p \leq 0.05$) negative slopes (change in pH over time) and lakes with significant positive slopes ($p \leq 0.05$) or slope not significant, by lake elevation (m) and current summer surface pH.

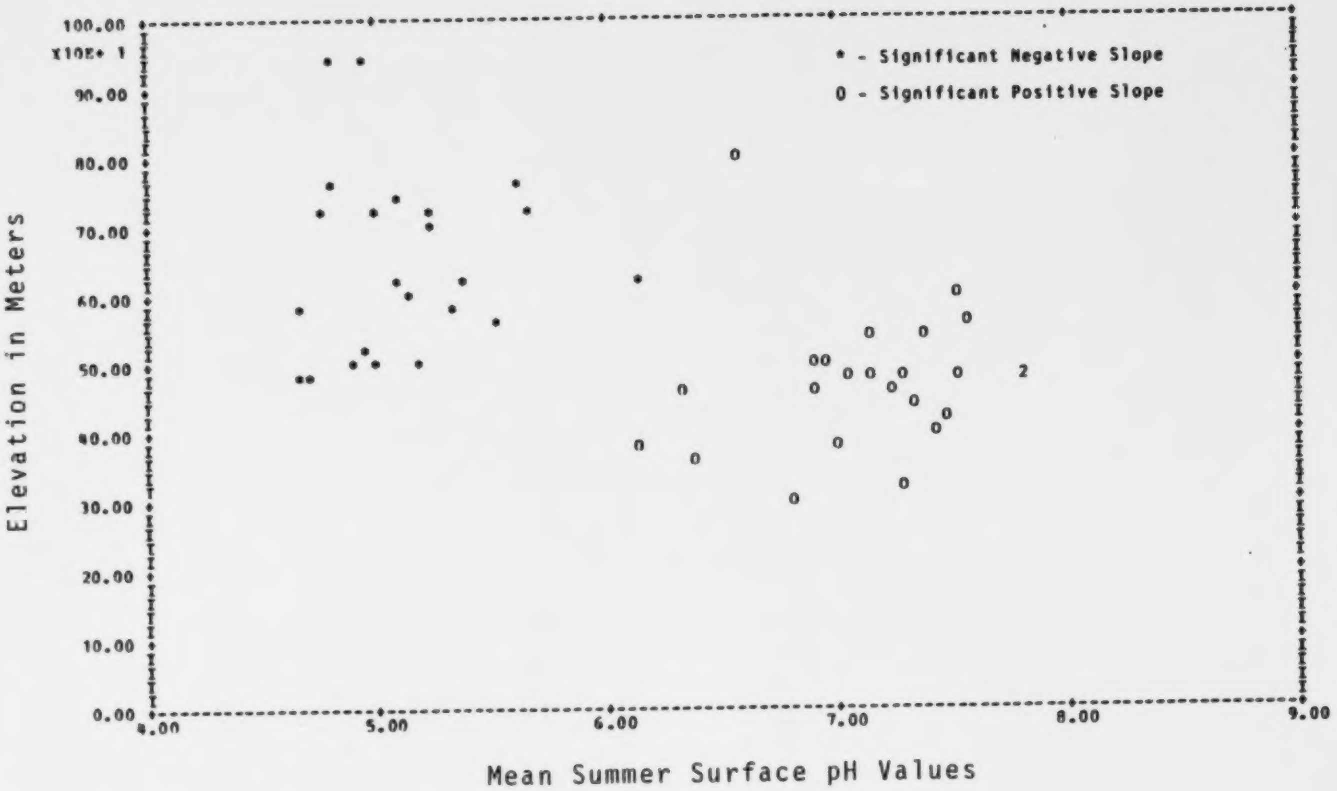

Figure 38. Distribution of lakes with significant ($p \leq 0.05$) negative slopes (change in pH over time) and lakes with significant ($p \leq 0.05$) positive slopes by lake elevation (m) and current summer surface pH.

H_0: Changes in pH over time ($\bar{b}_1$) have been similar in clear- water lakes (visual color <1.5) and highly colored lakes (visual color >2.5).

Rejection of the null hypothesis in favor of the alternative hypothesis:

H_1: Changes in pH over time have been greater in clear-water lakes than in lakes colored light brown or brown

would provide some support for the premise that waters with high concentrations of dissolved organics are less sensitive or insensitive to acidic deposition. Rejection of the null hypothesis in favor of a second alternative hypothesis:

H_2: Changes in pH over time have been greater in lakes colored light brown or brown than in clear-water lakes

would suggest that factors associated with high concentrations of dissolved organics, perhaps expansion of bog/wetland environs as proposed by Retzsch et al. (1980), may be responsible in part for the observed acidification of Adirondack waters.

Of the 650 lakes with sufficient data for assessment of trends in pH over time, 334 have observations of visual color. For 23 lakes, observations of visual color have been inconsistent (visual color 1.5-2.5); these lakes have been excluded from further analyses. For clear-water lakes (visual color <1.5) in the Adirondacks (n = 135) estimates of rate of change in pH over time (b_1) range from -0.76 to 0.92 pH units per decade, with a mean of 0.00 ± .05 pH units per decade. For lakes classified as light brown or brown (visual color >2.5) (n = 176), estimates of rate of change range from -1.27 to 0.84 pH units per decade, with a mean of +0.01 ± .05 pH units per decade (Figure 39). Thus, although the mean slope ($\bar{b}_1$) is slightly lower for clear-water lakes than colored waters, estimates of rate of change in pH are not significantly (p >0.05) different in the two groups and the null hypothesis cannot be rejected. Limiting the analysis to lakes most likely to have been affected by acidic deposition, lakes with current pH <5.0 (Figure 40) and/or at high elevations (≥ 610 m) (Figure 41), yields similar results. In both cases, the mean values in the two groups are not significantly (p >0.05) different and the null hypothesis cannot be rejected. For both high elevation and low pH lakes, however, decreases in pH over time are slightly greater in waters colored light brown or brown than in clear-water lakes.

Almer et al. (1978), Schindler and Turner (1982) and others have speculated that acidification is accompanied by increased water clarity and/or decreased water color. Decreases in pH (and associated increases in aluminum) may alter the structure of aquatic humus (and its ability to absorb light) or enhance precipitation of organic matter from the water column. Observations of visual color for Adirondacks lakes in the 1930's were compared to observations since 1960 as a rough test of the hypothesis that water color may have decreased through time. No trend toward decreased water color was apparent. Of the 117 lakes with data for the 1930's and post-1960 and classified as clear (visual color <1.5) or light

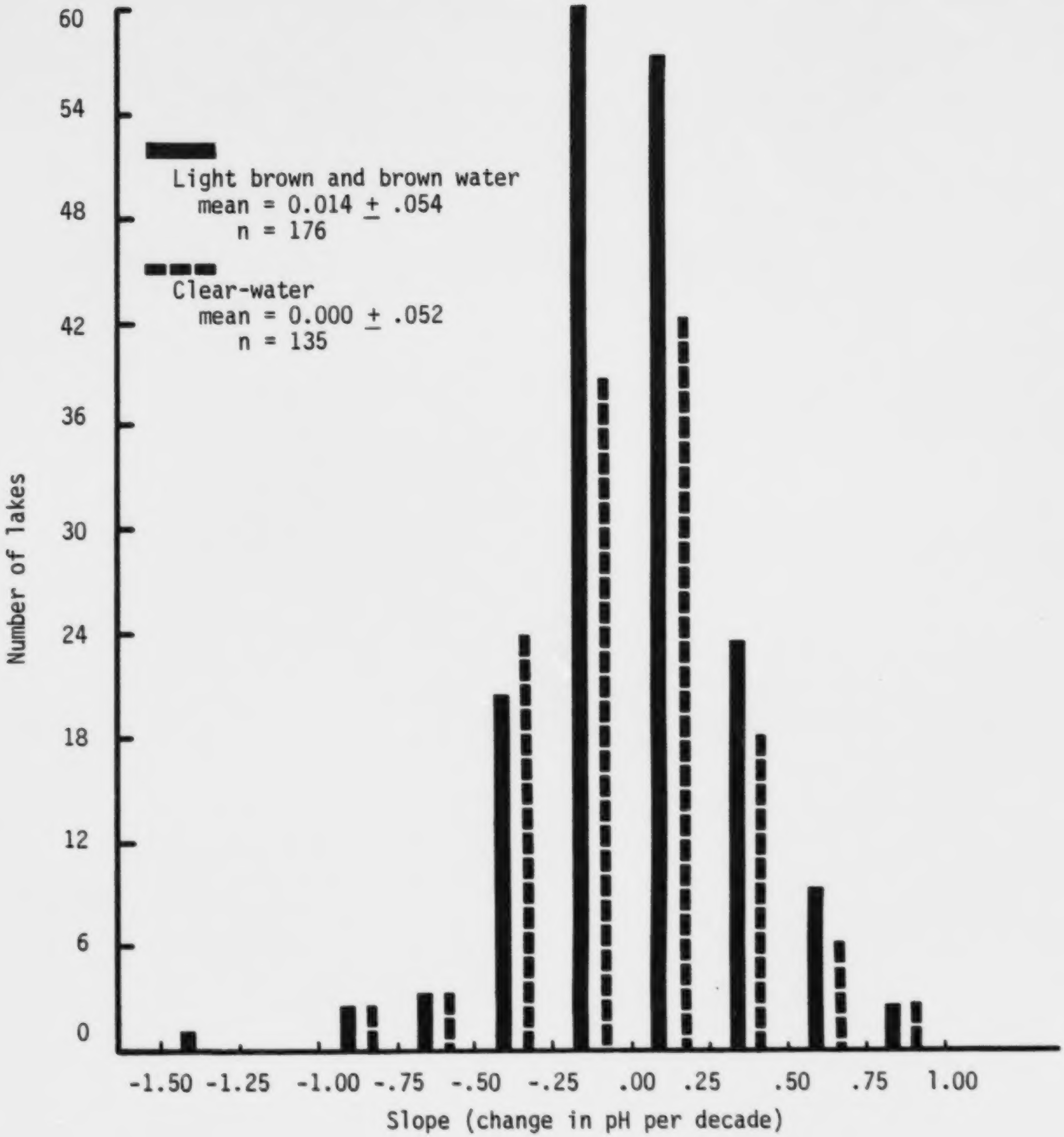

Figure 39. Frequency distribution of slope (change in pH over time) for clear-water lakes (visual color <1.5) and lakes classified as light brown or brown (visual color >2.5).

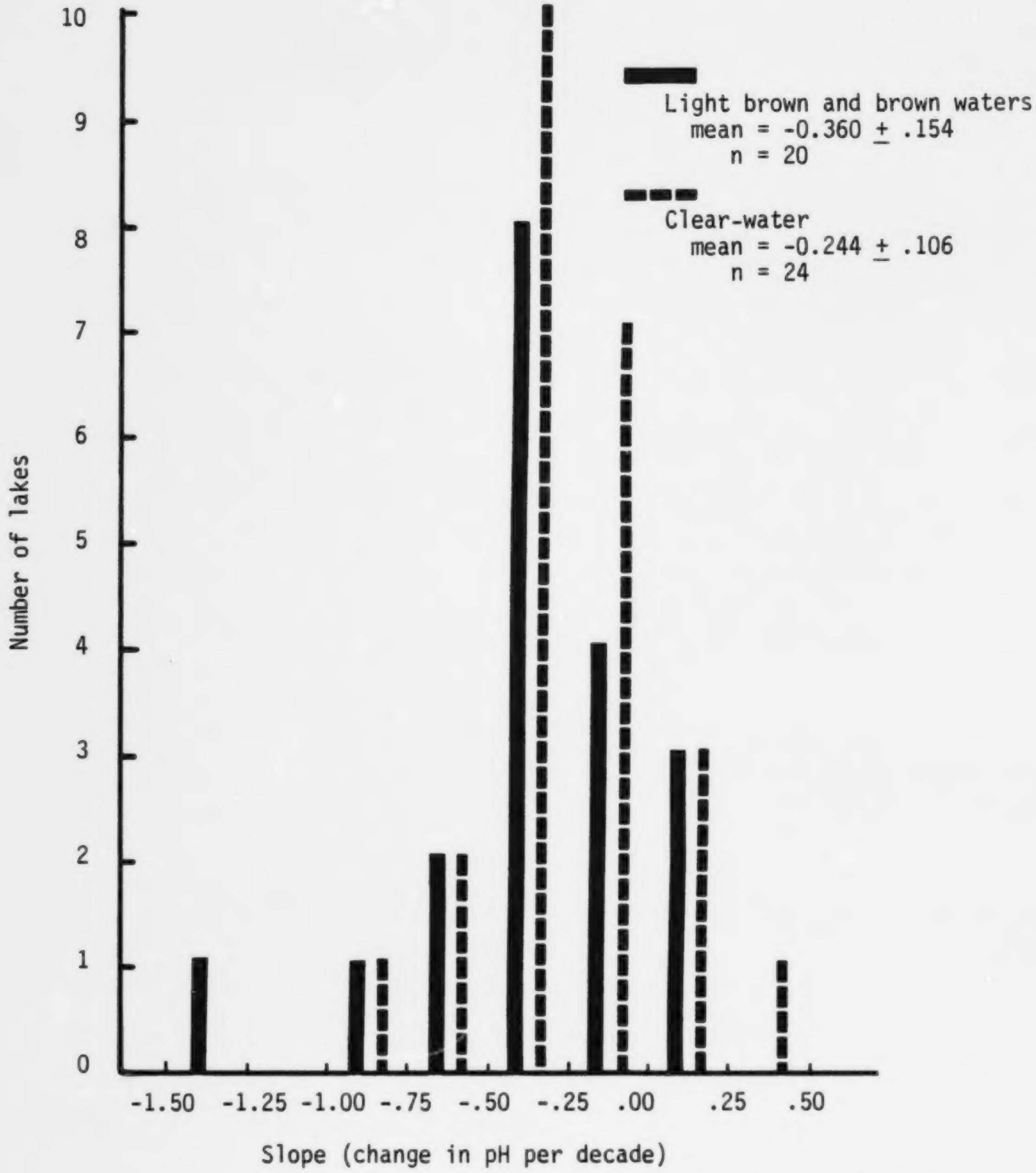

Figure 40. Frequency distribution of slope (change in pH per decade) for clear-water lakes (visual color <1.5) with current summer surface pH <5.0 and lakes classified as light brown or brown (visual color >2.5) and pH <5.0.

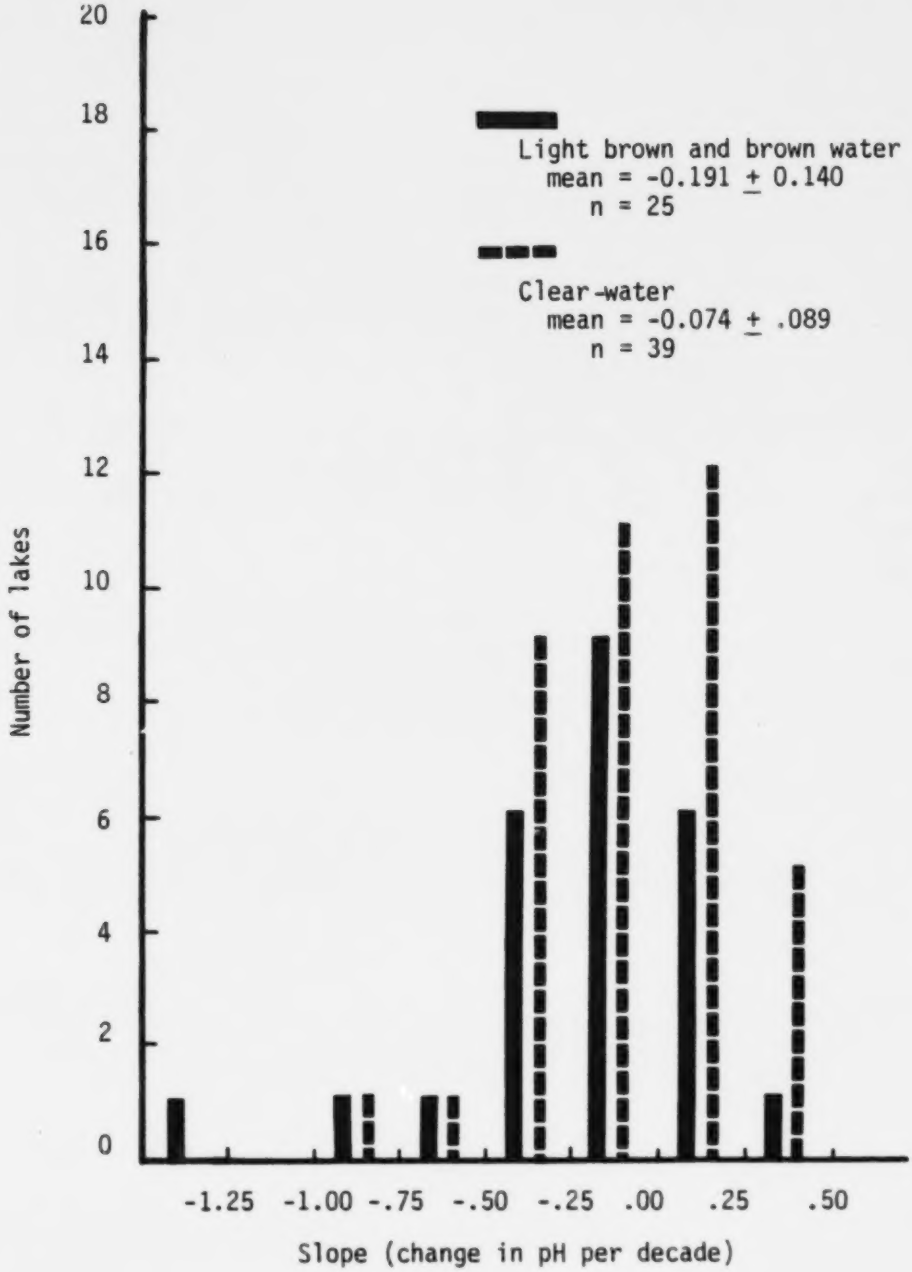

Figure 41. Frequency distribution of slope (change in pH over time) for clear-water lakes (visual color <1.5) at high elevations (>610m) and lakes classified as light brown or brown (visual color >2.5) at high elevations.

brown to brown (visual color >2.5), 20 lakes (17%) shifted from light brown/brown to clear from the 1930's to post-1960, 23 (20%) shifted from clear to light brown/brown, and 74 (63%) did not change. Results were similar for high elevation lakes, lakes currently acidic, and lakes with apparent decreases in pH over time.

7. IS THERE EVIDENCE THAT ADIRONDACK FISH COMMUNITIES HAVE BEEN ADVERSELY AFFECTED BY ACIDIFICATION?

For the 604 Adirondack lakes with adequate survey data, fish community status was evaluated as described in section III (Procedures for Assessment of Fish Population Status). The 'condition' of the community was ranked on an ordinal scale from 0 to 5 considering: (1) the severity of change in community composition through time (e.g., numbers of fish populations lost), (2) the quality and quantity of data available for assessing changes in community composition through time, and (3) the likelihood that any observed change in community composition resulted from acidification. Thus increasing rank from 0 to 5 is indicative of both increasing evidence for major decreases in species richness (loss of populations) and increasing probability that the observed changes occurred as a result of acidification. The likelihood that changes resulted from acidification was judged principally on (1) whether the observed changes were consistent with the pattern expected to occur with acidification, i.e., species expected to be acid-sensitive affected first, and (2) lack of evidence for alternate explanations for community change, in particular change in stocking policy, community interactions including introductions of predators or competing species, and reclamation. Fish community status was evaluated without information on lake identity or water chemistry. The ranking scale for fish community status was summarized in section III. Briefly, ratings of 0 and 1 denoted little or no change in the fish community over time; effects of acidification unlikely. A rating of 2 was considered marginal, some evidence of change in composition, some suggestion that the decline may be due to acidification, but evidence questionable. Communities rated 3, 4, or 5 were considered likely to have been affected by acidification, with an increasing rating 3 to 5 reflecting the increasing severity of the effect. For both ratings 4 and 5, survey data indicated that all or most fish populations in the lake had been lost.

Fish communities in 358 lakes were rated as zero, 133 as one, 64 as two, 23 as three, 18 as four, and 8 as five (Figure 42). Thus if these ratings truly reflect adverse effects of acidification, 49 fish communities (rated 3-5) of the 604 with adequate data (8.1%) appear to have been adversely affected by acidification. Some or all of the 64 communities (10.6%) rated 2, may have been adversely affected.

Evidence that acidification is in actuality adversely affecting fish communities in the Adirondacks, however, requires at the least some proof that these ratings of fish community status are doing what they were designed to do, i.e., evidence that these rankings are correlated with chemical variables indicative of acidification and/or acidity status. Evaluations of fish community status were made blindly, with no information on water chemistry or acidity status. Thus, a significant correlation

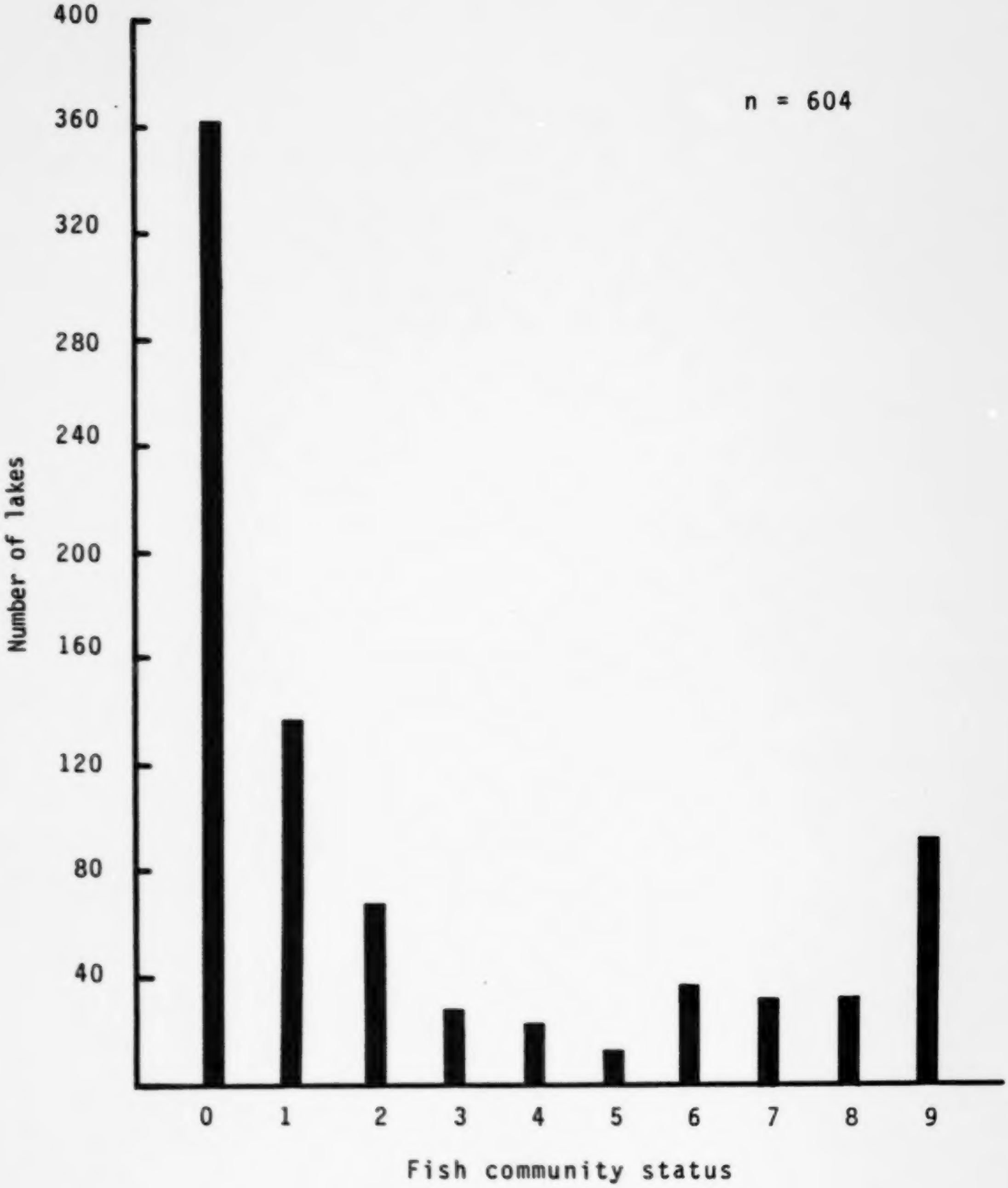

Figure 42. Frequency distribution: Number of lakes with fish community status rated 0 to 5.

between fish community status and lake acidity or acidification, while not proving cause and effect, would add credence to the argument that fisheries declines have occurred in the Adirondacks as a result of acidification. If the fish community status ratings are in error and actually reflect fisheries declines resulting from changes in stocking policies, increased fishing pressure, resurgence of beaver populations, or other factors as proposed by Retzch et al. (1982), there is no reason to expect fisheries decline and the rating of fish community status to be related to lake acidity or acidification. Rejection of the null hypothesis:

> H_0: The status of fish communities in Adirondack lakes (ranked on an ordinal scale 0 to 5) varies independently of lake pH and changes in lake pH over time.

for the alternate hypothesis:

> H_1: Fish community status (ranked on an ordinal scale 0 to 5) is negatively correlated with lake pH and changes in pH over time

is therefore considered evidence that acidification has adversely affected some fish communities in the Adirondacks.

7.1. Correlation with Lake pH

Mean pH values and associated 95% confidence intervals for lakes with community status rated 0 to 5 are plotted in Figure 43. It is obvious that pH and community status are significantly correlated: Analysis of variance in pH indicates that class means (among rankings of community status) are significantly ($p \leq 0.01$) different. Multiple t-tests confirm, as suggested in Figure 43 and in the definition of the community status rating, that pH levels for lakes with community status 0 and 1 are not significantly ($p > 0.05$) different. pH levels of lakes rated 2 are significantly ($p \leq 0.05$) lower than pH levels for lakes rated 1; those rated 3 are significantly ($p \leq 0.01$) lower than those rated 2, and pH levels for lakes rated 3, 4, and 5 are not significantly different.

Community Status Rating	0	1	2	3	4	5
Mean 5-year pH	6.26	6.10	5.79	5.16	5.15	4.95

The differences between pH levels for lakes with community status rated 1 and 2, however, are not large, and with a t-value corrected for multiple comparisons are not significantly different at $p \leq 0.05$.

Lake pH values used in the above analyses are average values for the 5-year period centered around the year in which the lake was last surveyed for fish. Thus these mean pH values incorporate for some lakes data from as early as 1958, for other lakes as late as 1984. As a result, it was not possible to limit analyses to specific pH methodologies. These 5-year mean pH values are averages of all pH measurements in the lake taken at 0-1 m depth over the 5 year period (although 1979 electrometric pH measurements have been excluded).

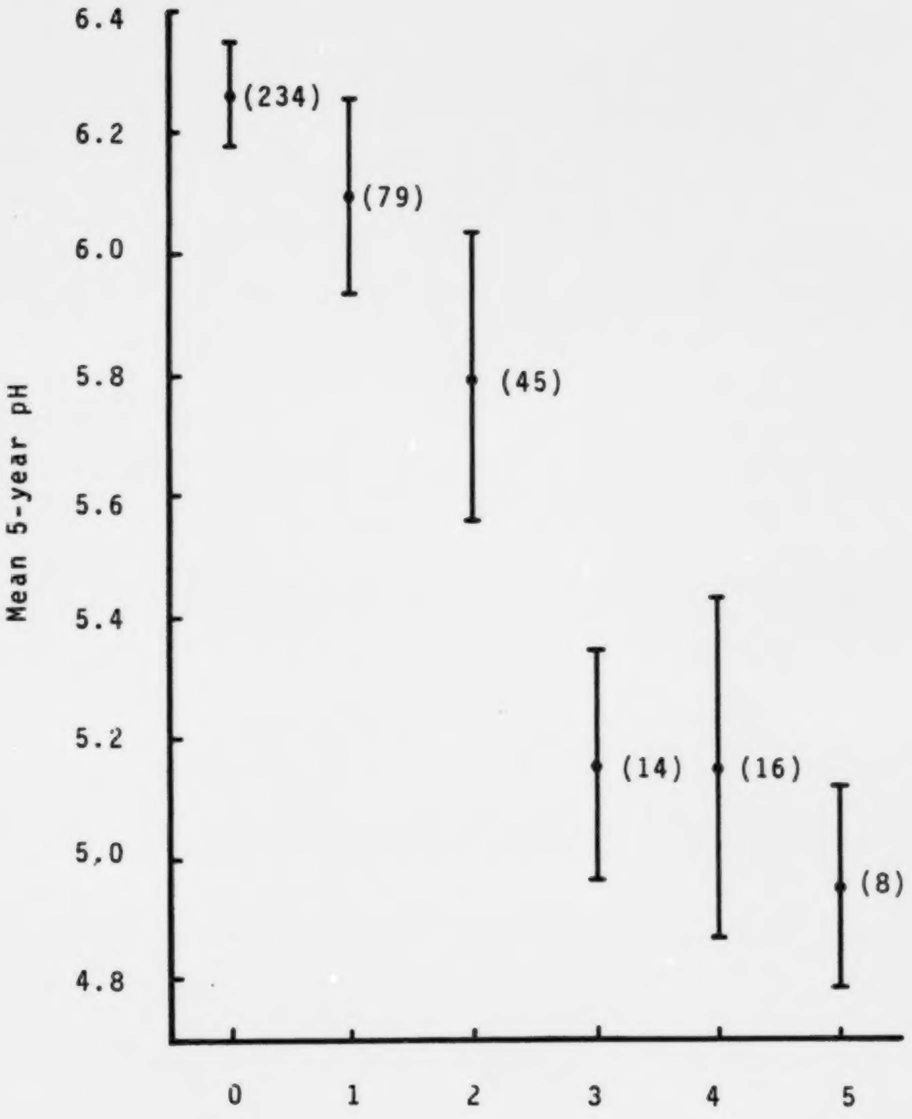

Figure 43. Mean pH (and 95% confidence interval) for lakes with fish community status ranked 0 to 5. Mean pH based on average value over 5 year period centered on year of last fish survey. Number of lakes in parentheses.

Variations in pH methodology undoubtedly add to the variance associated with the estimate of lake pH. Alternatively we could restrict analyses to specific pH methodologies, preferably electrometric, air-equilibrated pH. Since electrometric pH measurements are only available for Adirondack lakes since the mid-1970's, only fairly recent estimates of lake pH would be available. We are concerned that comparisons between recent water chemistry data and fisheries data that may date only through 1960 would introduce errors into our analyses. Thus generally for comparisons between fish population or community status and concurrent water chemistry, the 5-year average pH (± 2 years around the year of the last survey) is used. For comparison with Figure 43, mean pH values and 95% confidence intervals for lakes with fish community status rated 0 to 5 have also been calculated using current (1974-1983) electrometric, laboratory air-equilibrated pH measurements (0-1 m depth, summer period only) (Figure 44). The relationship between current pH and fish community status is similar to that based on the 5-year average pH, although lakes with community status rated 2 cannot be distinguished from lakes with community status rated 0 or 1. Restriction of the analysis to lakes with post 1973 fish surveys yields an identical pattern.

The community status rating incorporates some information about the quantity of data available for assessing trends, as a criterion for ranking. Restricting the analysis to lakes with greater numbers of fish surveys over more years (Figure 45) does not change the shape of the relationship between fish community status rating and pH, although the 95% confidence intervals are widened as sample size decreases.

7.1. Correlation with pH Change Over Time

In contrast to the strong and consistent correlation between fish community status and lake pH (either the 5-year average or current pH, 1974-1983), ratings of fish community status and the rate of change in pH over time (slope of the linear regression line) are only weakly associated (Figure 46). Analysis of variance in rate of pH change (slope) indicates that class means (among rankings of community status) are different only at $p \leq 0.10$. Grouping lakes with community status rated 3, 4 or 5, however, the mean slope for the group ($\bar{b}_1 = -0.12$ pH units per decade) is significantly ($p \leq 0.05$) less than zero (decrease in pH over time):

$$P(-0.19 \leq \bar{b}_1 < -0.04) = 0.95$$

Lakes rated 0, 1, or 2, on the other hand, have a mean slope ($\bar{b}_1 = 0.04$ pH units per decade) significantly greater than zero (increase in pH over time):

$$P(0.01 \leq \bar{b}_1 \leq 0.06) = 0.95$$

In addition rates of change in pH in the two groups (Figure 47) are significantly different from each other (t-test, $p \leq 0.01$).

Since the rate of change in pH over time is in itself not harmful to fish, perhaps it is understandable that the rate of pH change is not as closely correlated to fish community status as is lake pH. Presumably the

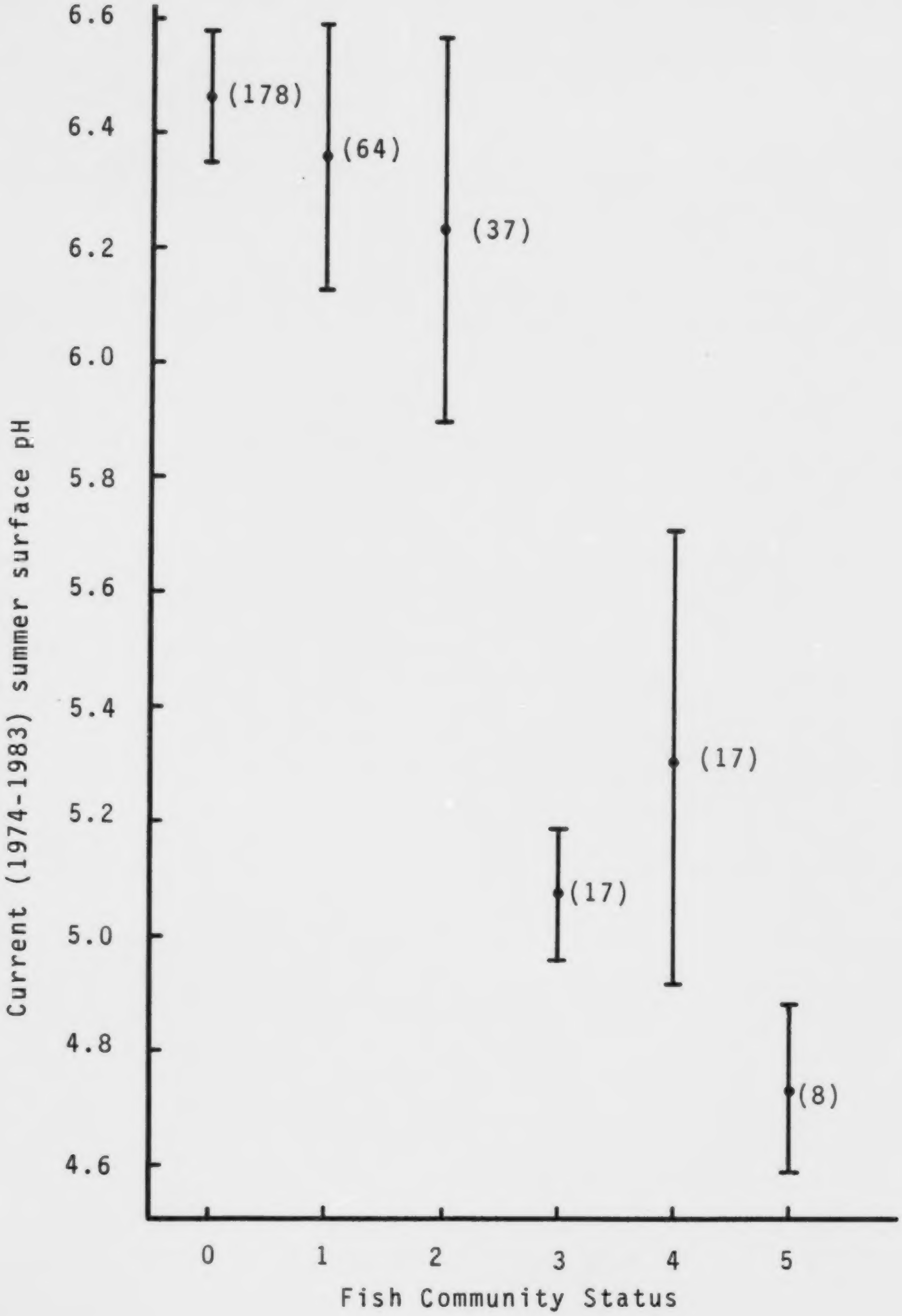

Figure 44. Current (1974-1983) summer surface pH (electrometric, air equilibrated) for lakes with fish community status ranked 0 to 5. Numbers of lakes in parentheses.

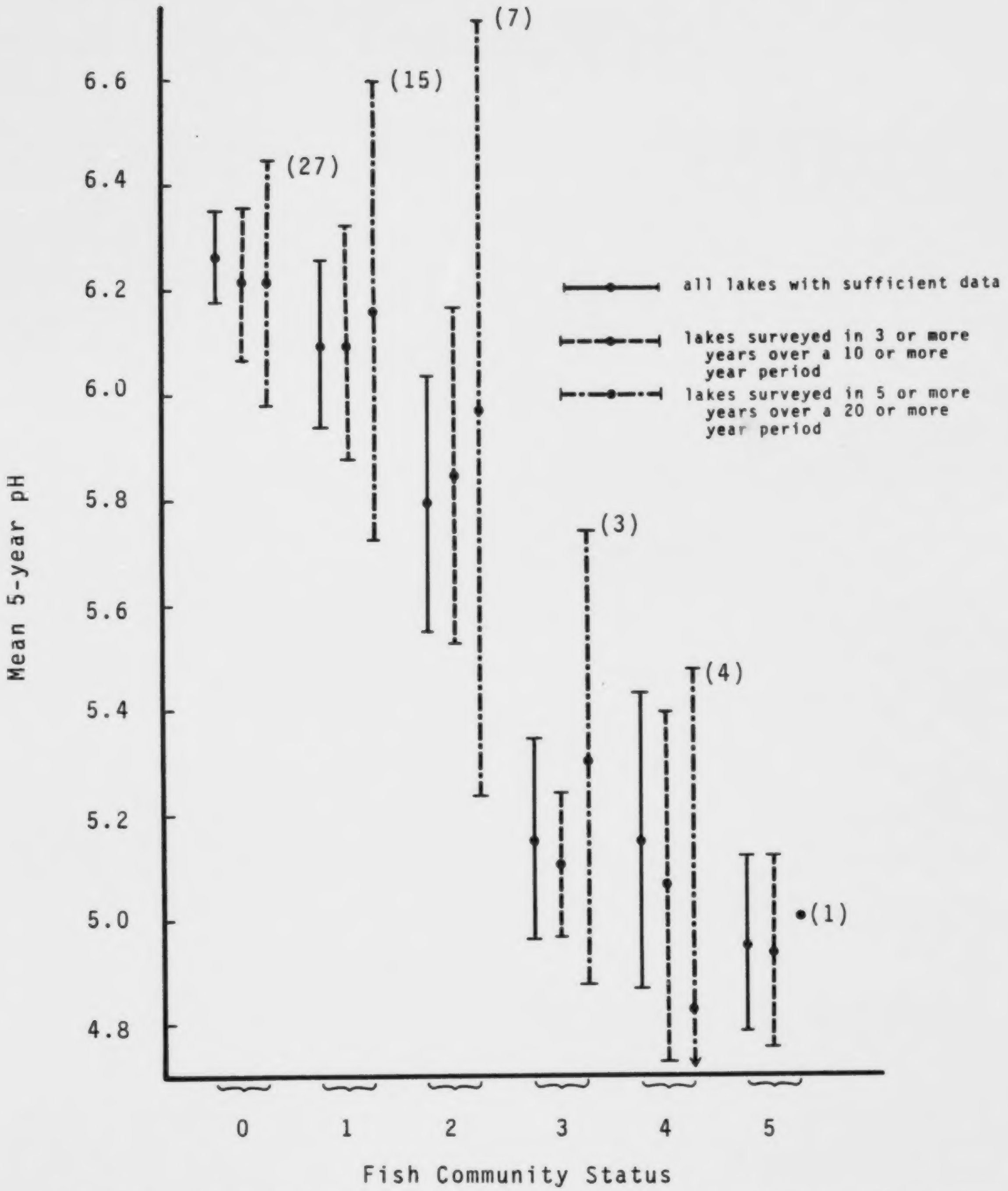

Figure 45. Mean (and 95% confidence intervals) 5-year pH for lakes with fish community status rated 0 to 5. Numbers of lakes with fish surveyed in 5 or more years over a 20 or more year period in parentheses.

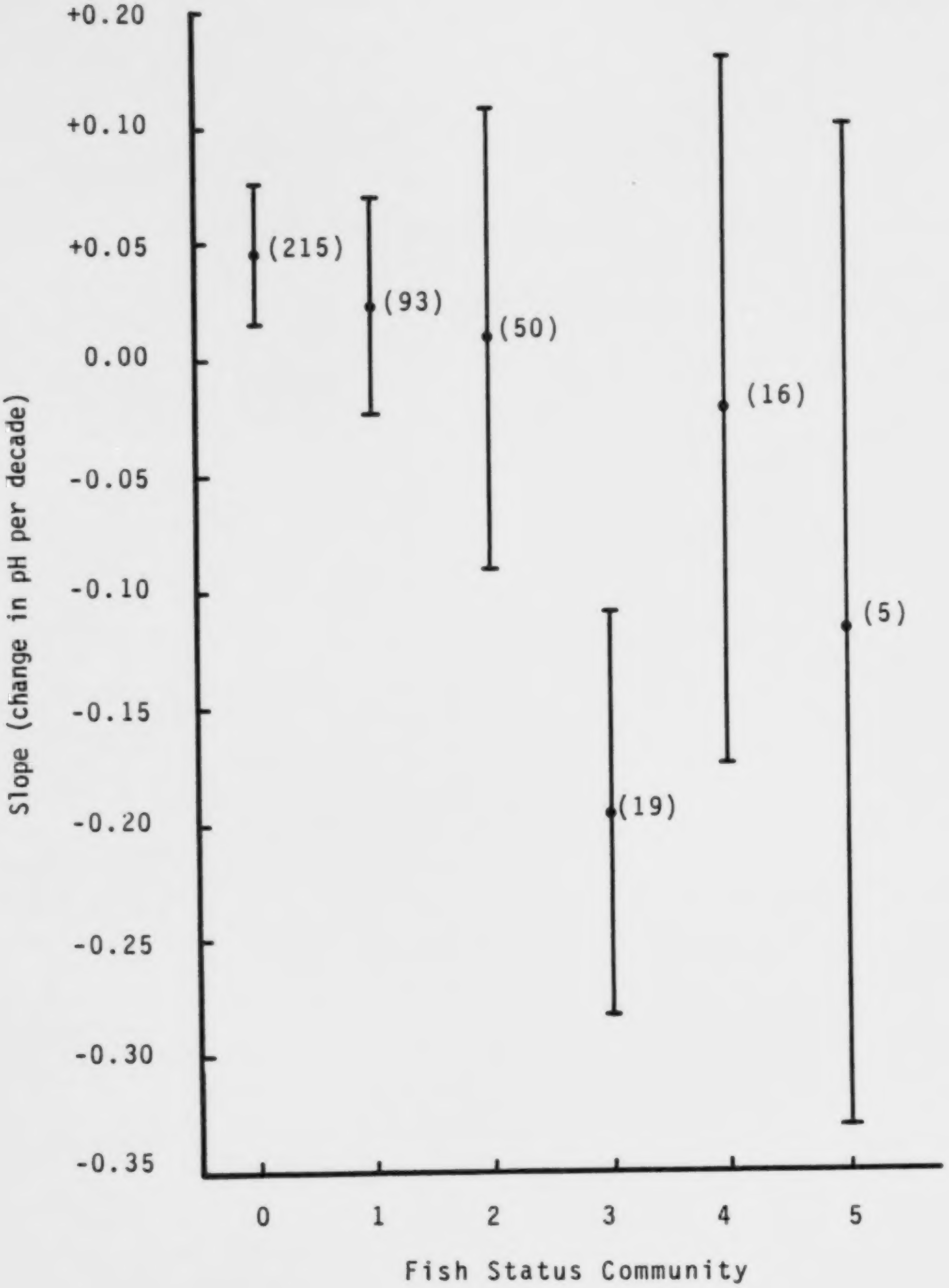

Figure 46. Mean (and 95% confidence interval) rate of change in pH over time (slope) for lakes with fish community status rated 0 to 5.

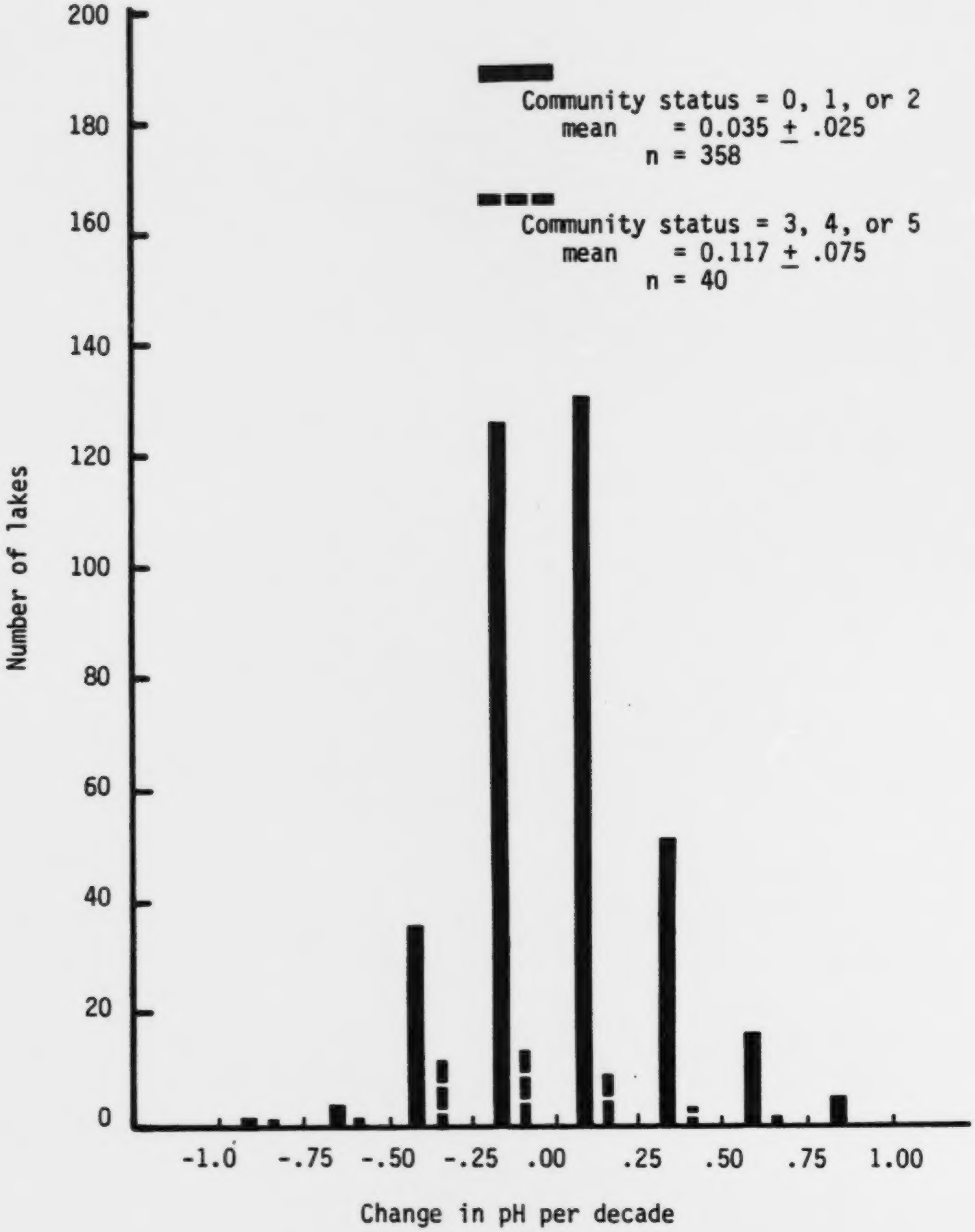

Figure 47. Frequency distribution: Rates of change in pH over time for lakes with fish community status rated 0-2 and 3-5.

best predictor of fish community status would be some combination of lake pH (at the time of the last fish survey), and rate of change in pH over time (Figure 48). Such does not, however, seem to be the case. In neither logistical regression (discussed in more detail later on) nor analysis of covariance with fish community status is slope (change in pH over time) significant (at $p \leq 0.05$) after adjusting for differences in lake pH.

Fish community status (incorporating changes in fish communities over time) is related principally to lake pH (current pH at the time of the last fish survey). In part this may reflect problems with our estimates of rate of pH change. As a result further discussions of the status of fish communities and fish populations focus principally on lake pH.

7.3. Variation in Fish Community Status

Although the proportion of lakes with fish community status rated ≥ 3 increases as pH decreases, there are still substantial numbers of lakes with relatively low pH (e.g., pH < 5.0) and apparently 'healthy' fish communities (i.e., rated 0 or 1) (Figure 49). Possible explanations include: (1) errors in classification of fish community status, (2) natural variance in pH response among fish communities, e.g., among fish community types, (3) variance in response related to the rate of change in pH over time, or (4) additional factors that modify the response of fish communities to pH.

Certainly some fish communities have been misclassified, as evidenced by the fact that lakes with pH as high as 6.04 had fish community status rated ≥ 3. Half of the lakes with pH < 5.0, however, had fish communities rated as apparently 'healthy'. As a group, these lakes tend to have been surveyed for fish somewhat more frequently (67% sampled 3 or more times) and more recently (80% have post-1975 survey data) than lakes in general with fish community status defined. Thus, it is unlikely that classification errors alone account for the large numbers of apparently 'healthy' fish communities at low pH.

Alternatively, it is possible that the variation in fish community status ratings at low pH accurately reflects the natural variation in the sensitivity of fish communities to pH. Given that these fish communities are composed of a diversity of species, a high variation in community response may not be unexpected. Twelve of the 15 lakes (80%) with pH < 5.0 and fish community status rated 0 or 1 were brook trout lakes (i.e., brook trout were the only game species present). Since brook trout tend to be fairly tolerant of low pH, it may be appropriate at pH < 5.0, particularly for pH 4.5-5.0, that only half of the brook trout communities have been adversely affected.

Perhaps lakes with low pH and 'healthy' fish communities have always been low pH, and populations in these lakes have adapted to acidic conditions. Indeed for lakes with pH < 5.0, the change in pH over time (slope of the linear regression line) was not significantly ($p > 0.05$) different from zero for lakes with fish community status rated 0 or 1, but was significantly less than zero:

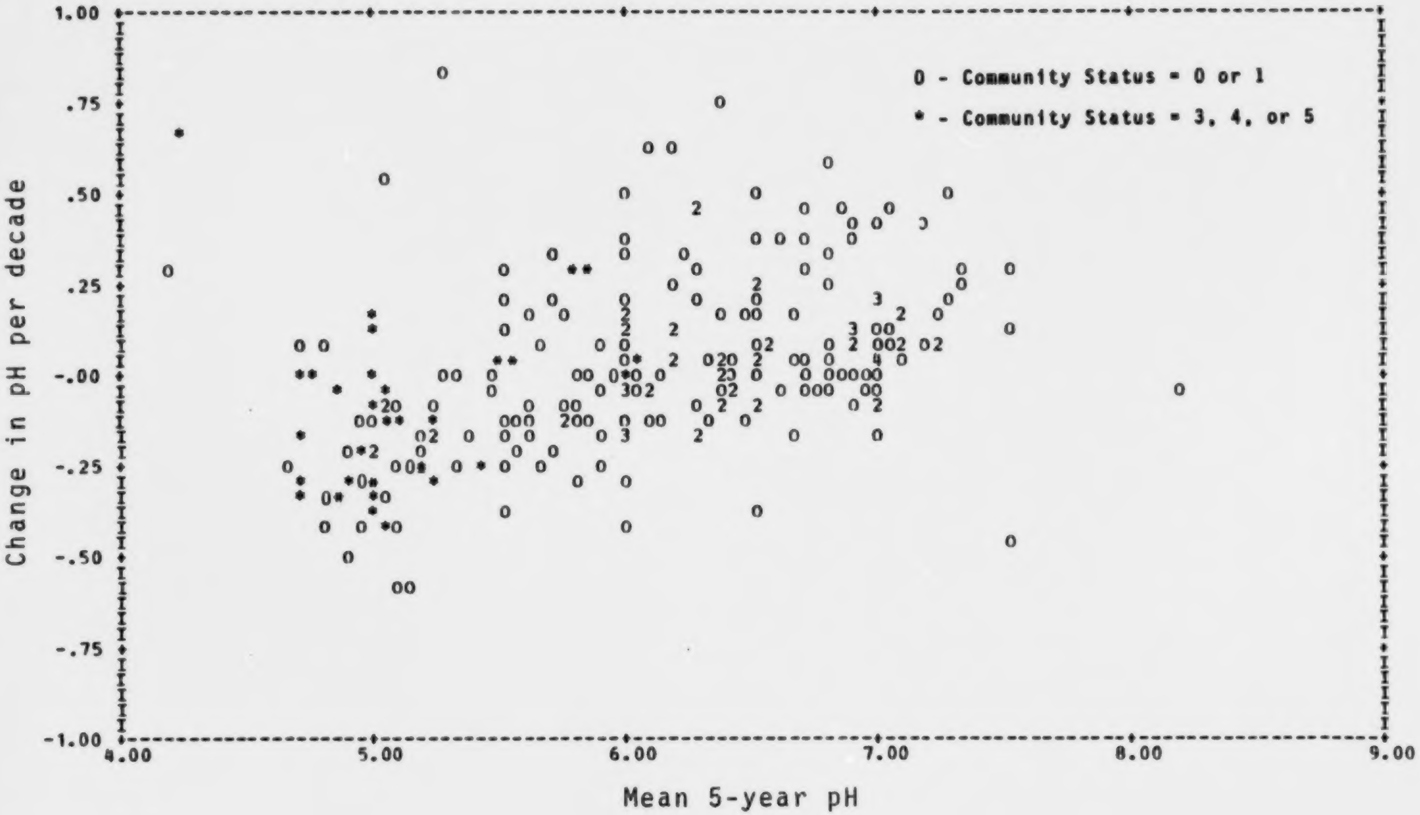

Figure 48. Distribution of fish community status by mean 5-year pH and rate of pH change over time.

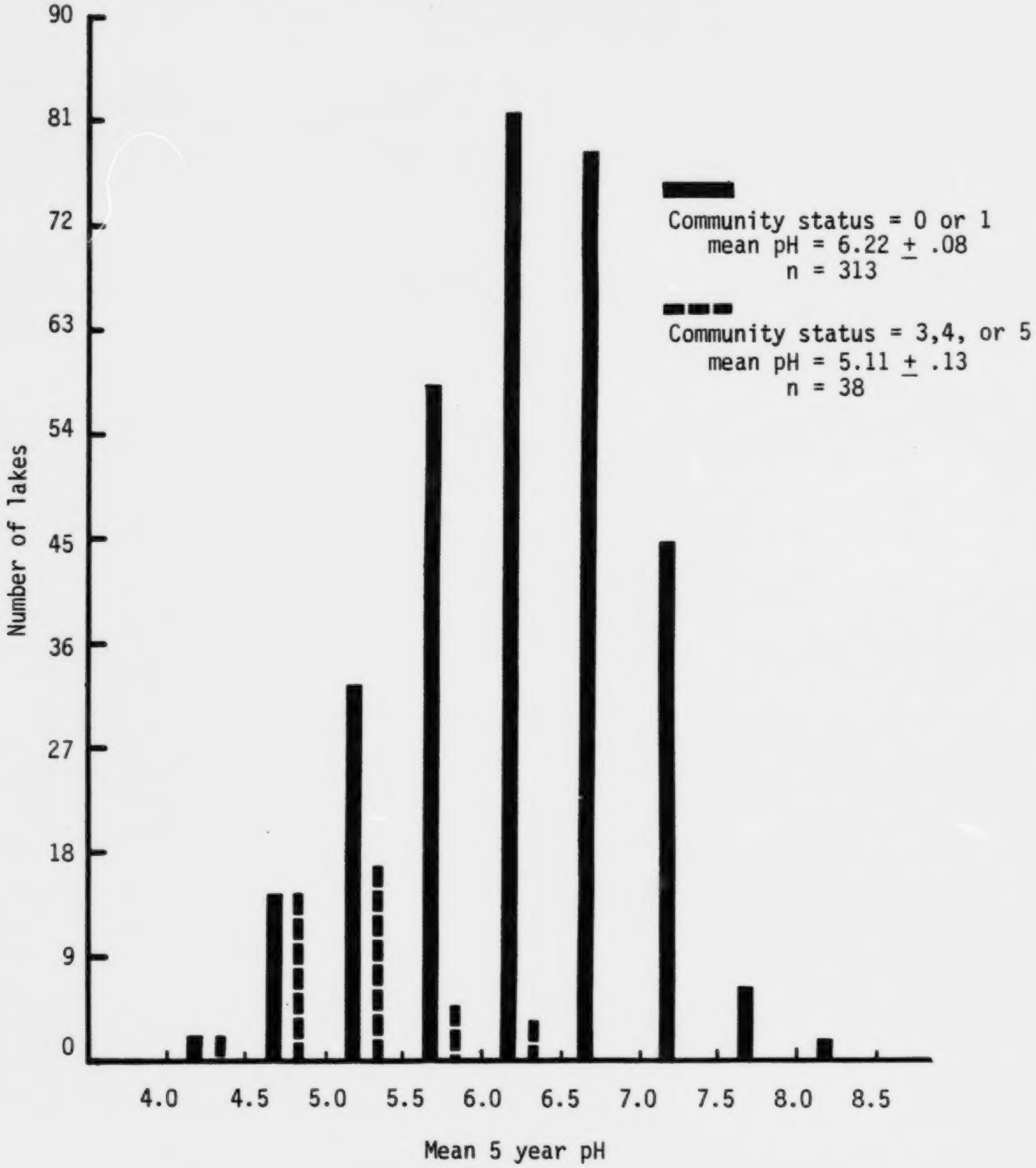

Figure 49. Frequency distribution of mean 5-year pH for lakes with fish community status = 0 or 1 and 3 to 5.

$$P\ (-1.32 \leq \bar{b}_1 \leq -0.26) = 0.95$$

for lakes with fish community status rated ≥ 3. As before, however, in analysis of covariance, after adjusting for differences in lake pH, differences in slope among rankings of fish community status were not significant ($p > 0.05$), neither for all lakes nor for lakes with pH < 5.0. Thus, there is some suggestion that low pH lakes with apparently 'healthy' fish communities have been acidic longer, but the evidence is not conclusive.

Finally, it is possible that additional factors, not yet considered in analyses, mitigate the effects of low pH in some waters. The potential influence of high concentrations of dissolved organics on fish community response in acidic waters is considered in section 9.

8. WHAT IS THE FUNCTIONAL RELATIONSHIP BETWEEN FISH COMMUNITY STATUS AND LAKE pH?

We are interested in quantifying the relationship between fish community status and lake pH. Typically dose-response relationships of this type are sigmoid. Usually, biological responses (e.g., in a bioassay) are related more closely to the logarithm of the dose (here, pH) than to the dose itself (H^+ concentration) (Ashton 1972). Examination of Figure 43 suggests that expressing fish community status as a sigmoid function of pH is probably appropriate. Commonly used sigmoid curves include the integrated normal curve, the logistic curve, the sine curve, and Urban's curve (Ashton 1972). Analysis of fish community status as a function of lake pH has therefore been based on the logistic regression model:

$$P = \frac{1}{1 + \exp[-(b_0 + b_1X)]}$$

where P = the probability of a given response
b_0 = the intercept parameter
b_1 = the regression coefficient
X = the independent variable, in this case pH.

All analyses have been performed with the LOGIST procedure (Harrell 1983) within SAS (Statistical Analysis Systems, SAS, Inc.). As before, unless otherwise noted these analyses use the average pH for the 5 year period centered around the year of the last fish survey.

Initially to simplify the analysis and interpretation of results, lakes were divided into two groups: (1) those with apparently healthy fish communities (i.e., fish community status rated 0 or 1), and (2) those with fish communities experiencing distinct declines in species richness over time, apparently as a result of acidification (i.e., fish community status rated 3, 4, or 5). In the later group, a substantial number and in some cases all of the fish populations had been lost from these lakes over time.

Lakes with fish community status rated as 2 (evidence unclear as to effects of acidification) were excluded from these initial analyses. A single binary (0-1) dependent variable was thus defined:

STATUS = 1 if fish community status = 0 or 1
STATUS = 0 if fish community status = 3, 4, or 5

The results of the logistic regression, status = f(pH), are plotted in Figure 50 as the predicted probability that status = 1 (fish community 'healthy') as a function of pH, including the 95% confidence limits on the predicted probability. The estimated model coefficients are:

Variable	Beta	Std. Error	Chi-Square	P
Intercept	-14.02	2.33	36.34	0.0000
pH	2.89	0.44	42.94	0.0000

the rank correlation between predicted probability and response = 0.810

$r = 0.588$

$n = 313$ for status = 1
$n = 38$ for status = 0

The adequacy of the logistic model is demonstrated by plotting, for a given probability (P), the true proportion of lakes with status = 1, for those lakes having a predicted probability $\geq$ P, as a function of the average predicted probability of those $\geq$ P (Figure 51). For reference, P = 0.50 at pH 4.8-4.9.

Variations on the above model include: (1) inclusion of lakes with fish community status = 2 into the definition of lakes with status = 1, (Figure 52) and (2) substitution of current (1974-1983) lake pH values for the 5-year average pH used in the above model (Figure 53). In the first case, since we have included 'marginal' populations (fish community status = 2) together with 'healthy' populations (fish community status = 0 or 1) in the class defined by status = 1, we would expect a shift of the predicted probability line to the left, towards lower pH levels. Examination of Figure 52 confirms that this is the case, with P = 0.50 now at pH about 4.7. In all other models using the status variable, status = 1 only when fish community status = 0 or 1.

Use of the 5-year average pH in the original model introduces potential errors associated with measurement of pH by a variety of methodologies. Restricting the analysis to only lakes with post-1973 fish surveys and using mean summer surface pH values for the period 1974-1983 based only on electrometric, air-equilibrated pH values, may reduce the variance associated with pH but also decreases the number of lakes available for analysis. The results of the logistic regression of status = f(pH), using pH as defined above, are very similar to the original model based on the 5-year average pH (Figure 53). The curve of predicted probabilities is shifted, however, slightly to the right (increasing pH) by approximately 0.1 pH units. Thus the reference point P = 0.50 now occurs

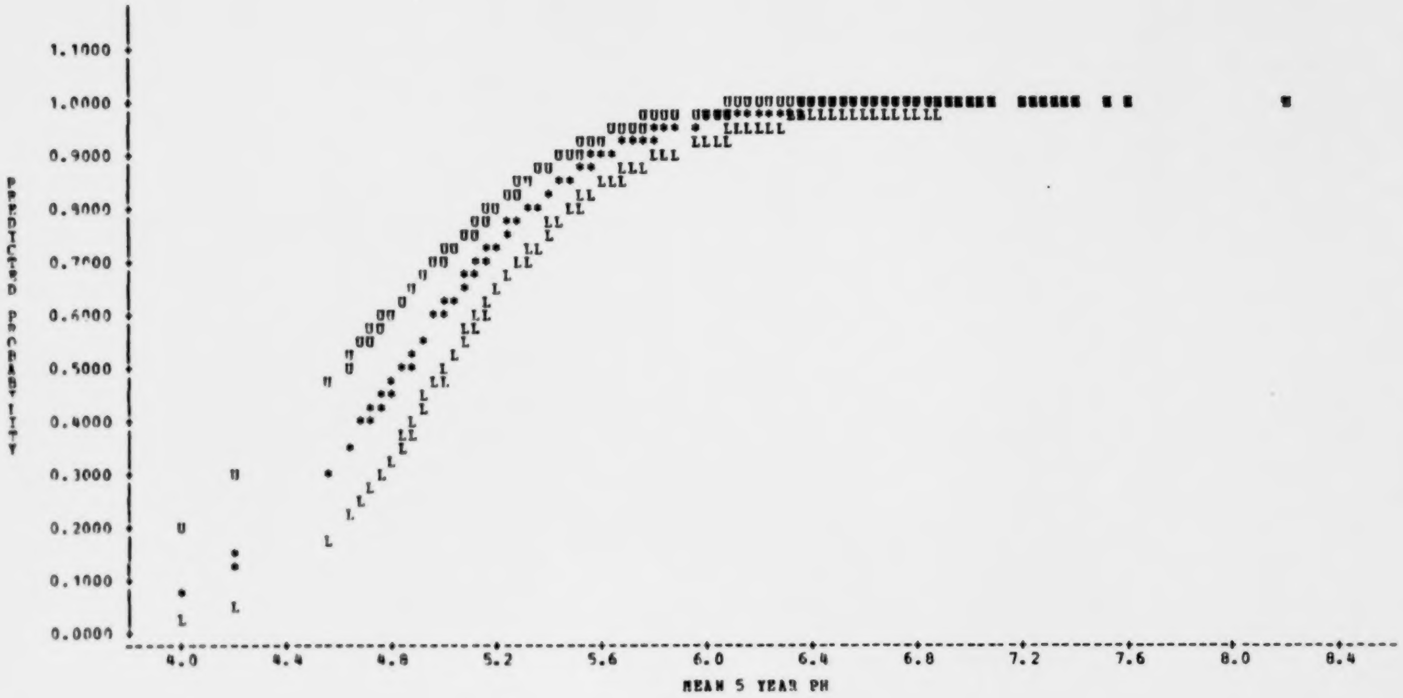

Figure 50. Predicted probability (and 95% confidence interval: U to L) that status = 1 (fish community 'healthy') as a function of mean 5 year pH. Status = 1 for lakes with fish community status rated 0 or 1.

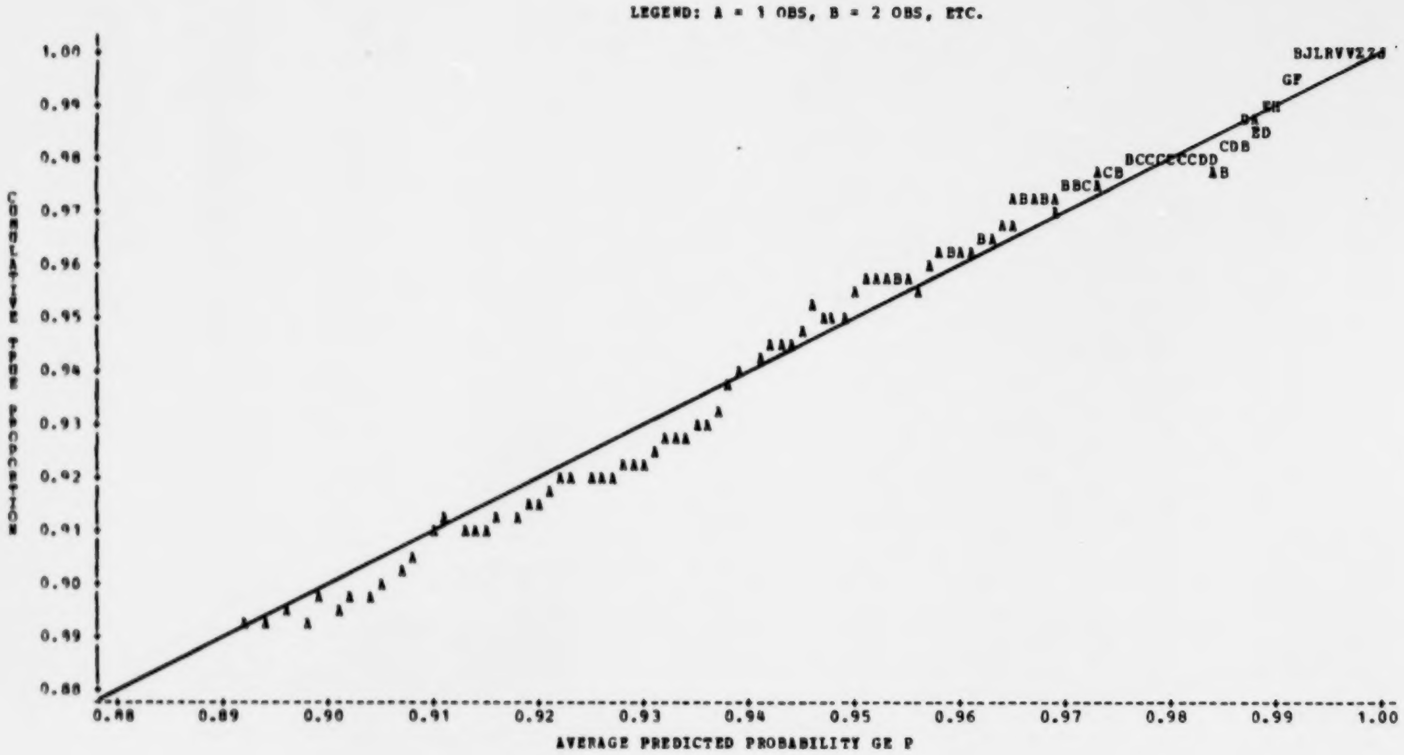

Figure 51. For a given probability, P, cumulative true proportion of lakes status = 1 for those lakes having a predicted probability $\geq$ P, as a function of the average predicted probability of those $\geq \hat{P}$. A 1:1 relationship is anticipated if the logistic model adequately represents the data.

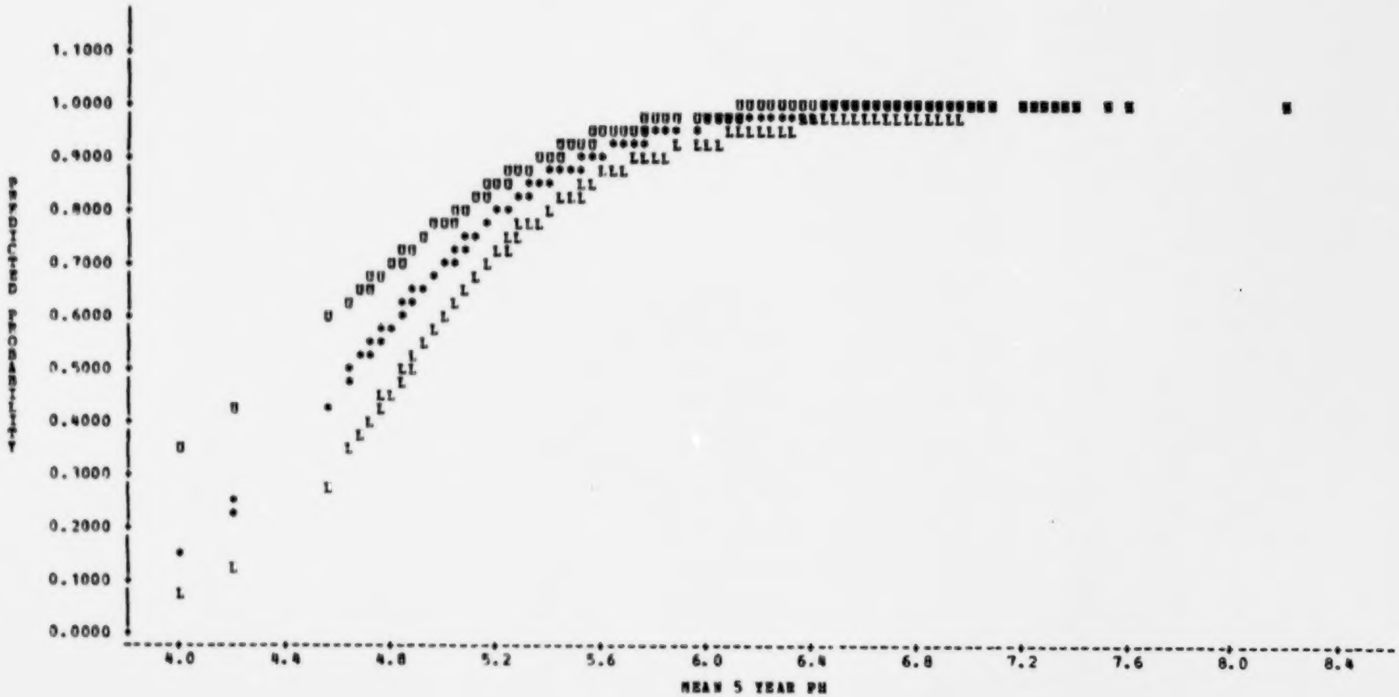

Figure 52. Predicted probability (and 95% confidence interval: U to L) that status = 1 (fish community 'healthy') as a function of mean 5-year pH. Status = 1 for lakes with fish community status rated 0, 1, or 2.

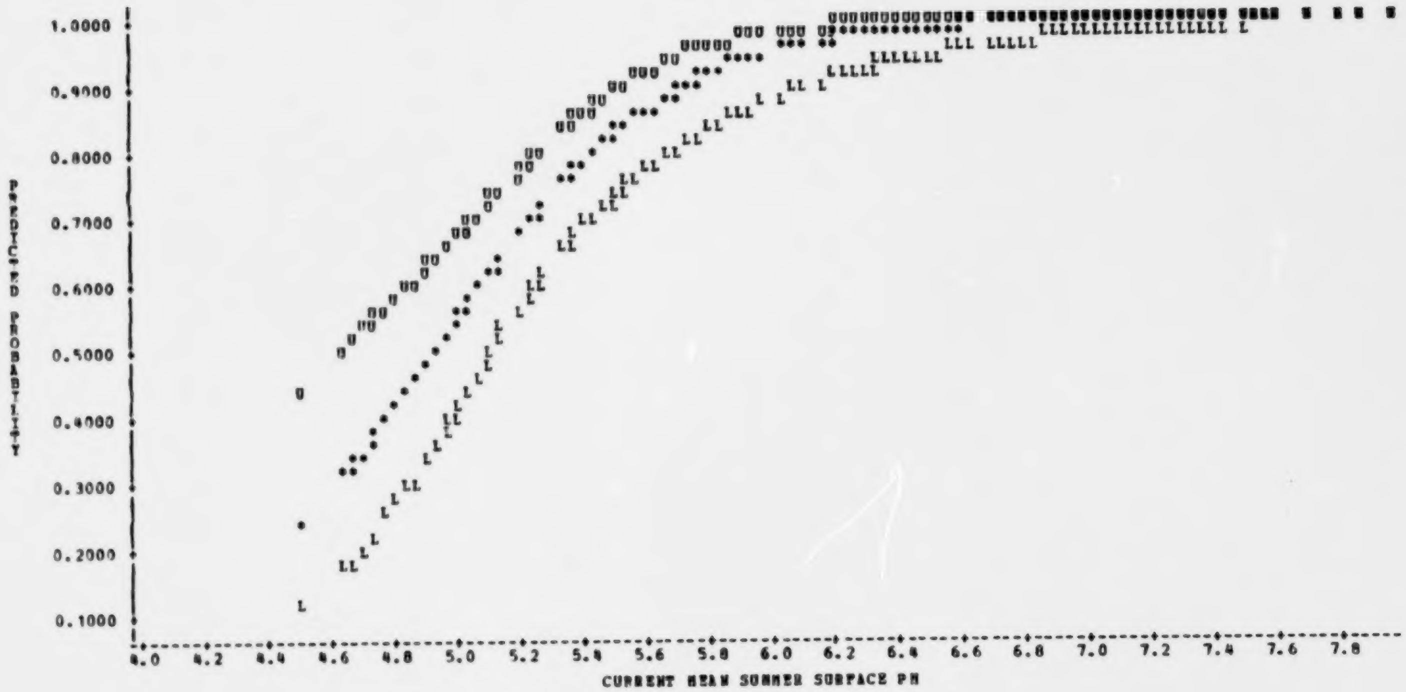

Figure 53. Predicted probability (and 95% confidence interval: U to L) that status = 1 (fish community 'healthy') as a function of current (1974-1983) mean summer surface pH (electrometric, air-equilibrated).

at pH 4.9-5.0. The estimated model coefficients are:

Variable	Beta	Std. Error	Chi-Square	P
Intercept	-13.48	2.88	21.93	0.0000
pH	2.74	0.55	24.92	0.0000

the rank correlation between predicted probability and response = 0.779.

r = 0.580
n = 163 for status = 1
n = 29 for status = 0

Analyses so far have not distinguished among fish community types. Given that species sensitivity to acidity varies greatly we would expect that fish communities dominated by different species would also vary in their response to acidification. Four community types have been distinguished: brook trout, coldwater, warmwater, and two-story (Pfeiffer 1979). A large portion of the lakes in the Adirondacks, particularly the smaller lakes at higher elevations, are classified as brook trout waters (Pfeiffer 1979), containing brook trout as the sole game fish and in some cases a variety of non-game fish particularly brown bullhead, white sucker, pumpkinseed sunfish and/or creek chub. Of the 351 lakes in the original analysis of fish community status as a function of pH, 220 of these (63%) were classified as brook trout waters. Thus it is not surprising that the relationships between fish community status and pH for brook trout waters (Figures 54 and 55) are similar to that for all lakes, all community types combined. The estimated model coefficients for the logistic regression are:

Variable	Beta	Std. Error	Chi-Square	P
Intercept	-11.86	2.52	22.14	0.0000
pH	2.46	0.48	26.35	0.0000

The rank correlation between predicted probability and response = 0.718

r = 0.516
n = 155 for status = 1
n = 30 for status = 0

Fifty-three lakes (15%) were classified as coldwater fish communities, supporting several salmonid species (including brook trout in many cases) but lacking warmwater game fish. Few of these lakes (9%, n = 5) had fish community status > 3 (Figure 56) or pH < 5.0. Thus, while estimation of the logistic model, status = f(pH), is possible, the confidence limits on the predicted probabilities are large (Figure 57):

Variable	Beta	Std. Error	Chi-Square	P
Intercept	-30.77	15.01	4.20	0.0404
pH	6.02	2.86	4.42	0.0356

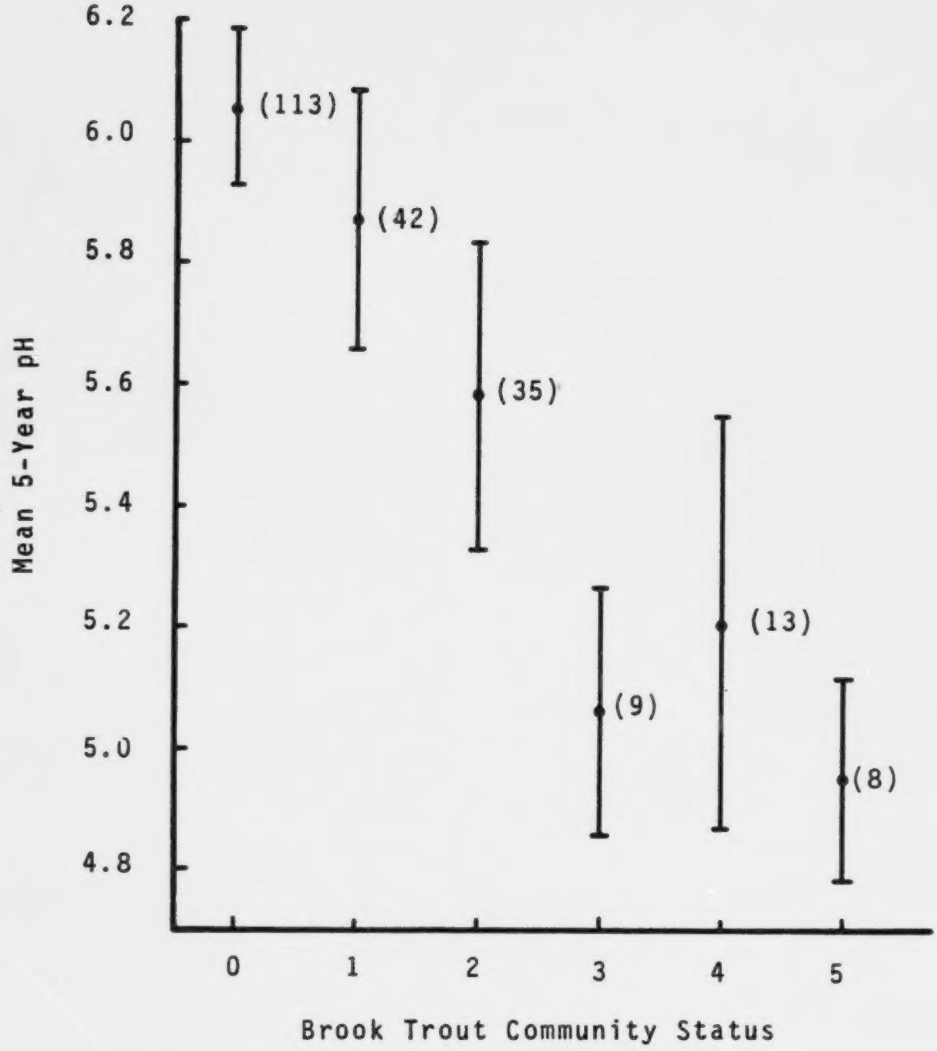

Figure 54. Mean pH (and 95% confidence intervals) for brook trout lakes with fish community status ranked 0 to 5. Mean pH based on average value over 5-year period centered on year of last fish survey. Number of lakes in parentheses.

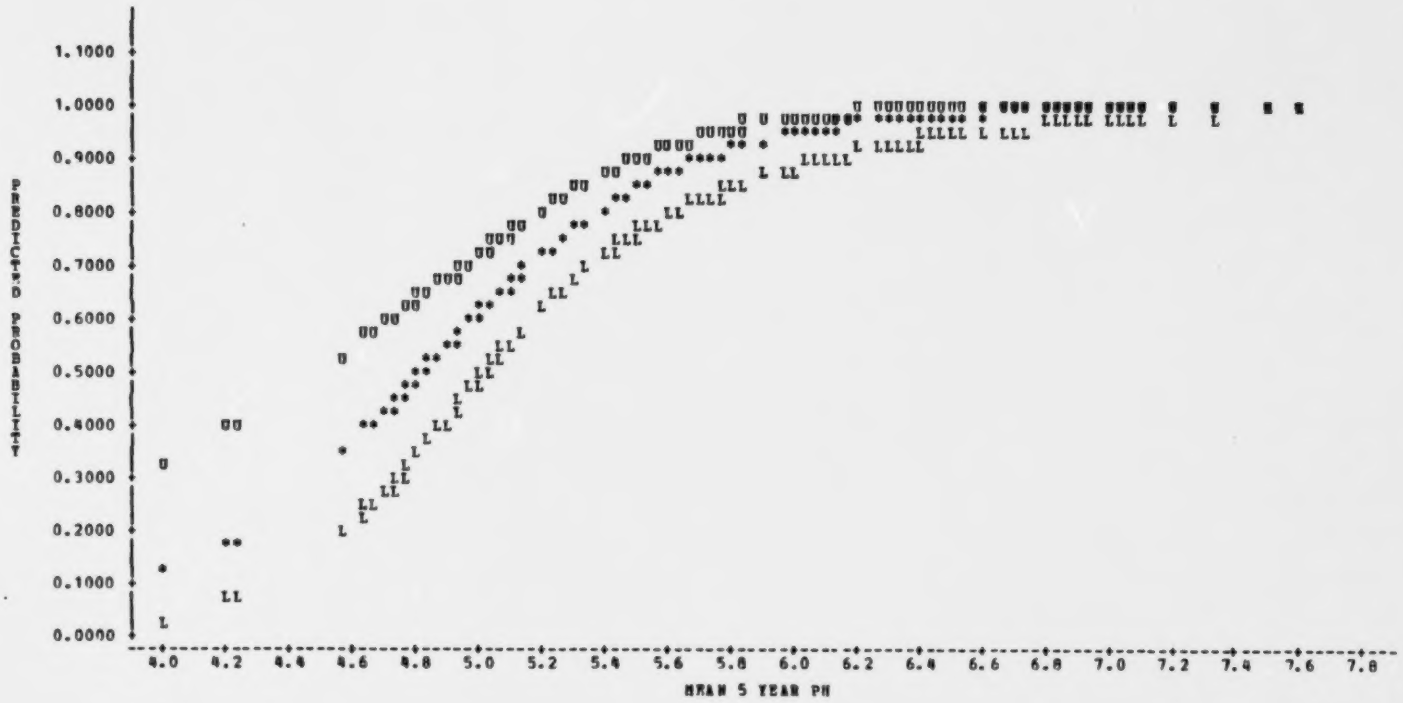

Figure 55. Predicted probability (and 95% confidence interval: U to L) that status = 1 (fish community 'healthy') as a function of mean 5-year pH, for brook trout waters.

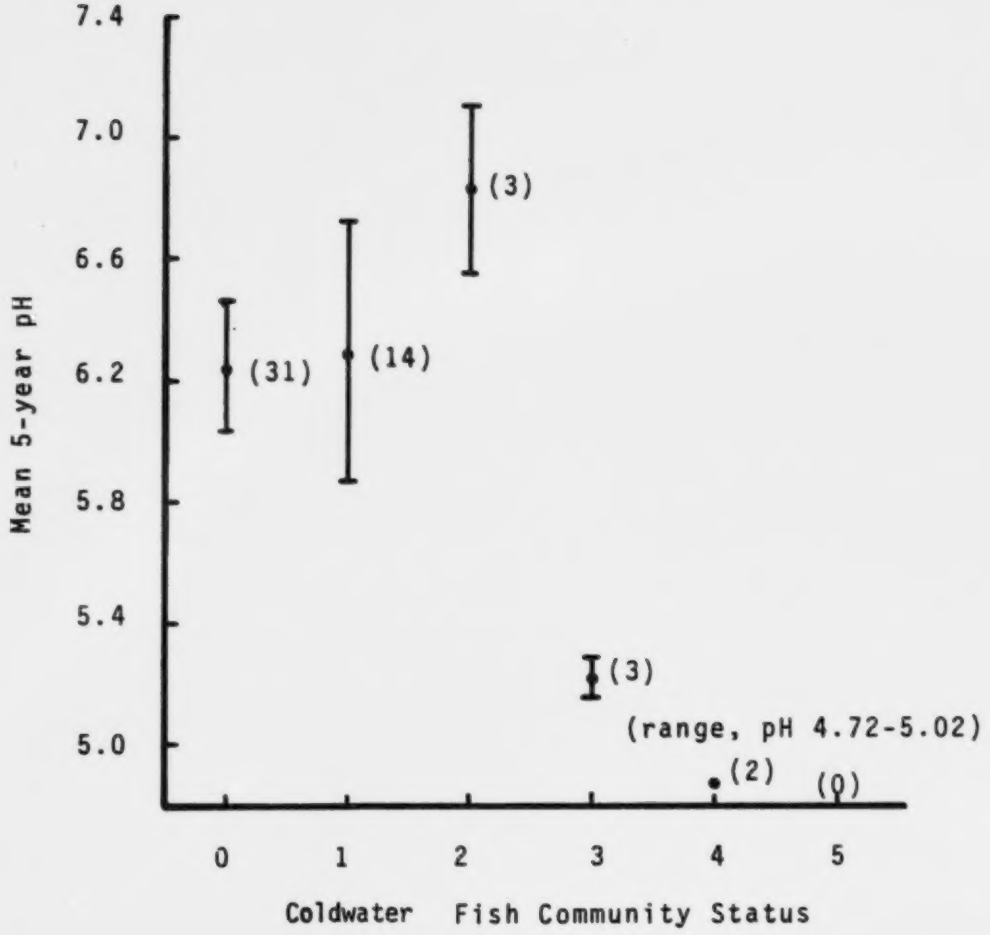

Figure 56. Mean pH (and 95% confidence interval) coldwater fish communities with fish community status ranked 0 to 5. Mean pH based on average value over 5-year period centered on year of last fish survey. Number of lakes in parentheses.

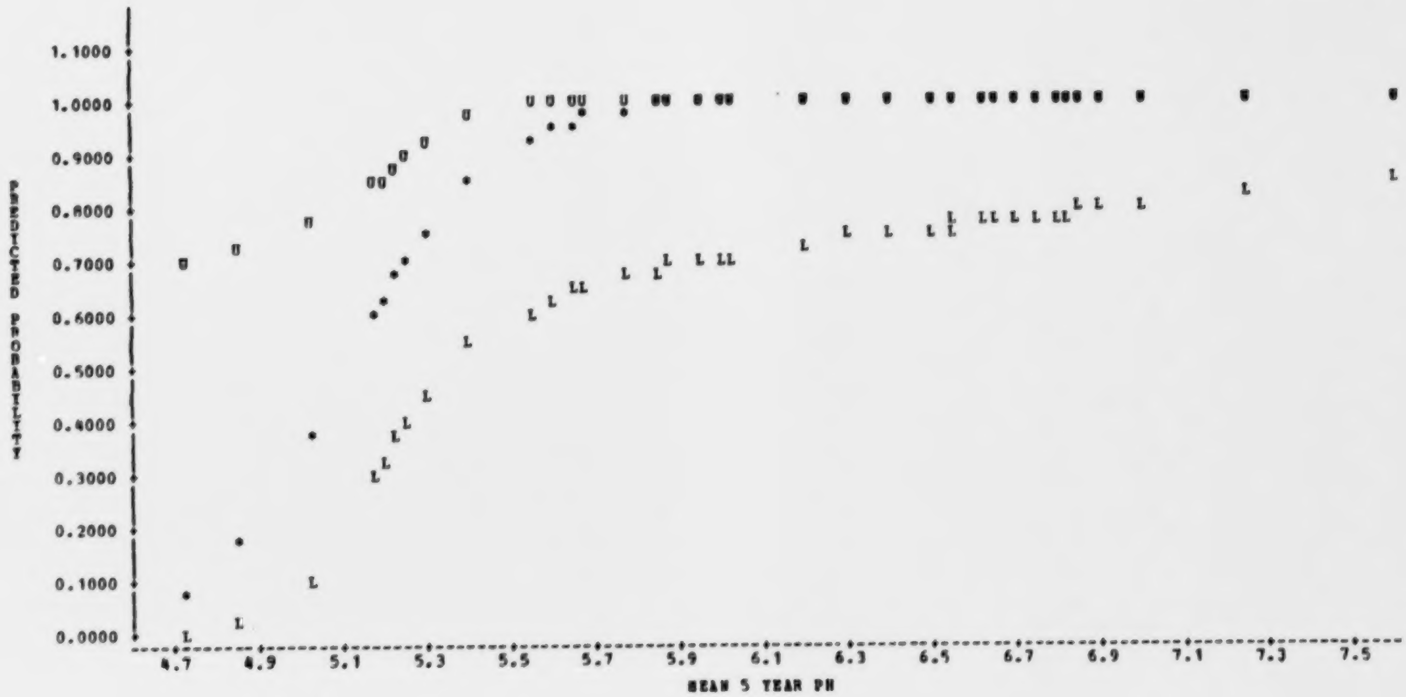

Figure 57. Predicted probability (and 95% confidence interval: U to L) that status = 1 (fish communtiy 'healthy') as a function of mean 5-year pH, for coldwater fish communities.

The rank correlation between predicted probability and response = 0.933

$r = 0.694$
$n = 45$ for status = 1
$n = 5$ for status = 0

It appears, however, that as expected the regression curve has shifted somewhat to the right, i.e., increasing pH. Our reference point, $P = 0.50$, occurs at approximately pH 5.1, as compared to pH 4.8-4.9 for brook trout communities. Since brook trout are generally considered the most tolerant of the salmonid species to acidity, we would expect that the mixed-trout coldwater fish communities might be more sensitive to pH than brook trout communities. Comparisons may, however, be easier on a species-by-species basis, discussed in later sections.

Neither two-story fish communities (mixed coldwater and warmwater game species) (41 lakes, Figure 58) nor warmwater fish communities (21 lakes, Figure 59) had any lakes with fish community status rated ≥ 3. Thus logistic regressions of status as a function of pH could not be calculated. Neither community type occurred in any lakes with pH < 5.5, and 95% of the lakes had pH ≥ 6.0. It is possible, therefore, that these community types are restricted to lakes with relatively high pH levels for reasons other than pH (or aluminum) toxicity.

The LOGIST procedure in SAS is also able to estimate logistic regression models for dependent variables on an ordinal scale, e.g., the ranking of fish community status from 0 to 5. In this case we need make no assumptions nor grouping of classes into two groups to define a single binary variable. Results from the logistic regression of fish community status as a function of pH (average for the 5-year period centered on the year of the last fish survey) are plotted in Figures 60-65. As expected, the predicted probability for higher rankings increases as the pH decreases. The estimated model coefficients are:

Variable	Beta	Std. Error	Chi-Square	P
Intercept1	6.41	0.88	52.65	0.0000
Intercept2	5.33	0.87	37.94	0.0000
Intercept3	4.29	0.85	25.37	0.0000
Intercept4	3.74	0.85	19.27	0.0000
Intercept5	2.54	0.89	8.15	0.0043
pH	-1.12	0.15	58.31	0.0000

The rank correlation between predicted probability and response = 0.371

$r = 0.256$
total observations = 396

Restricting the analysis to lakes with post-1973 fish survey data and defining pH as the mean summer surface pH 1974-1983, based only on electrometric, air-equilibrated pH measurements (Figure 66) modifies these relationships slightly, although the pattern of response is quite similar:

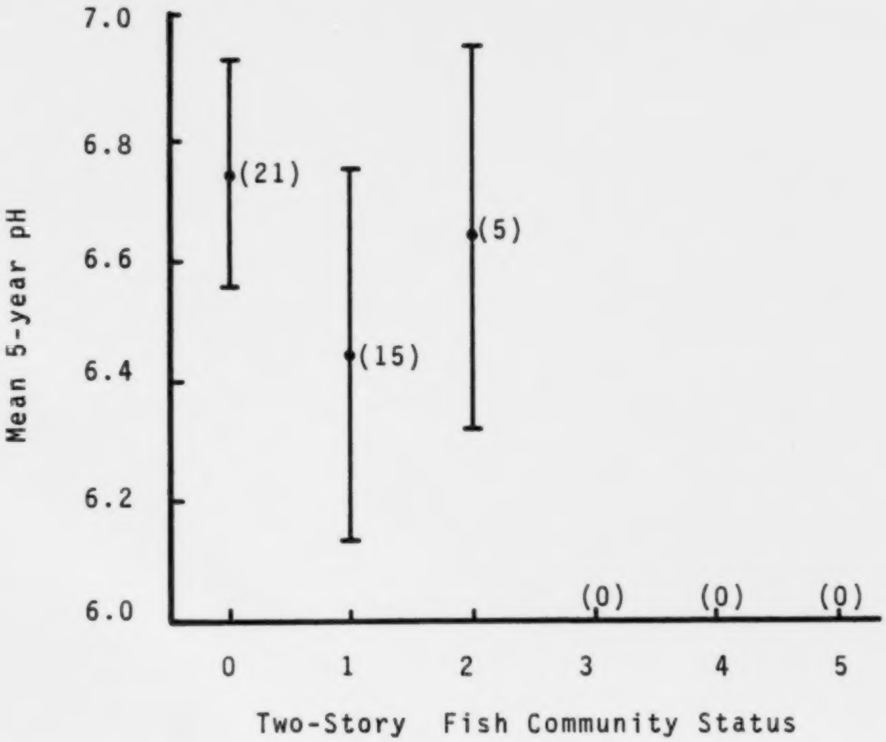

Figure 58. Mean pH (and 95% confidence interval) for two-story lakes with fish community status ranked 0 to 5. Mean pH based on average value over 5-year period centered on year of last fish survey. Number of lakes in parentheses.

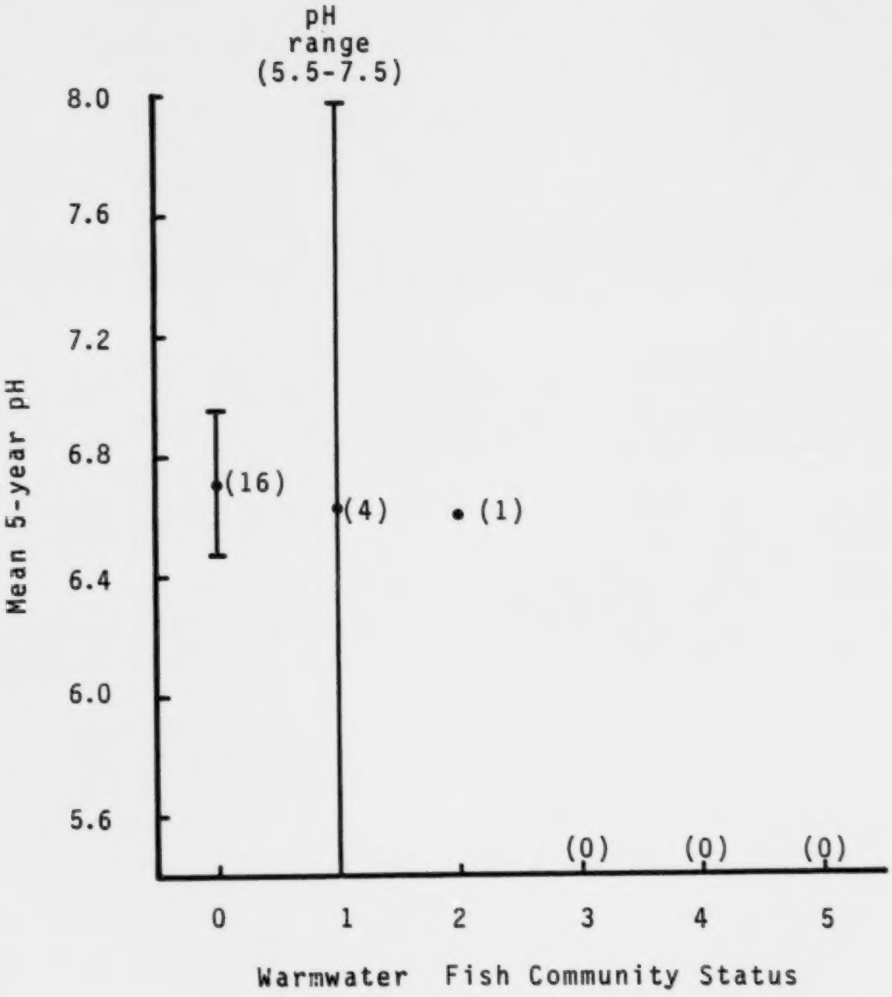

Figure 59. Mean pH (and 95% confidence interval) for warmwater fish communities with fish community status rated 0 to 5. Mean pH based on average value over 5-year period centered on year of last fish survey. Number of lakes in parentheses.

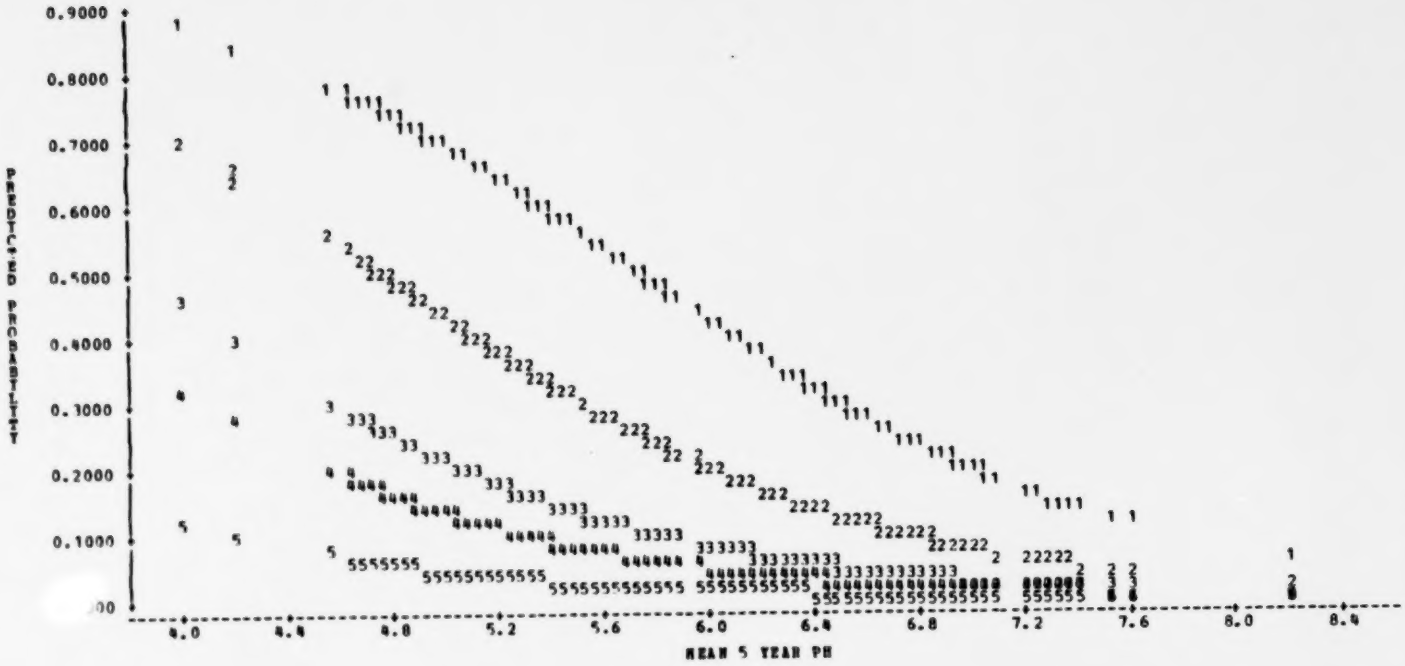

Figure 60. Predicted probability that fish community status ≥ s (for s 1 to 5) as a function of mean 5-year pH.

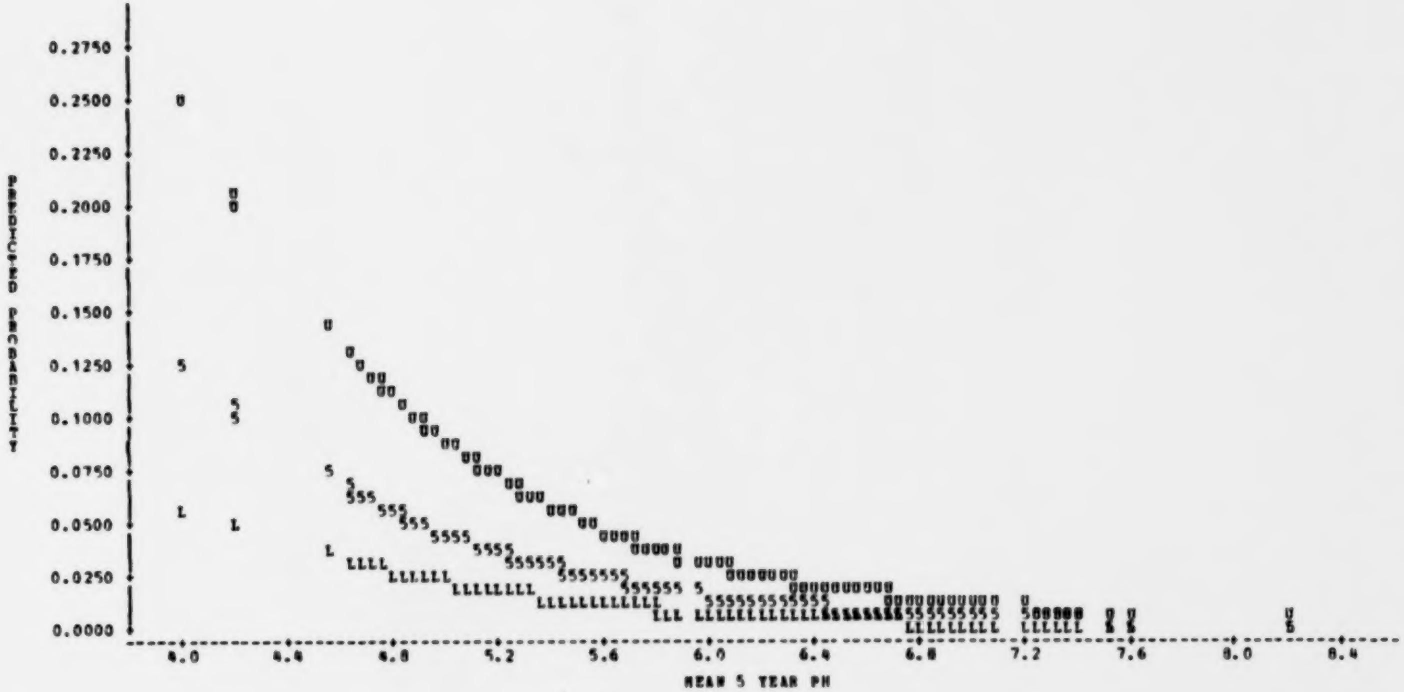

Figure 61. Predicted probability (and 95% confidence interval: U to L) that fish community status = 5, as a function of mean 5-year pH.

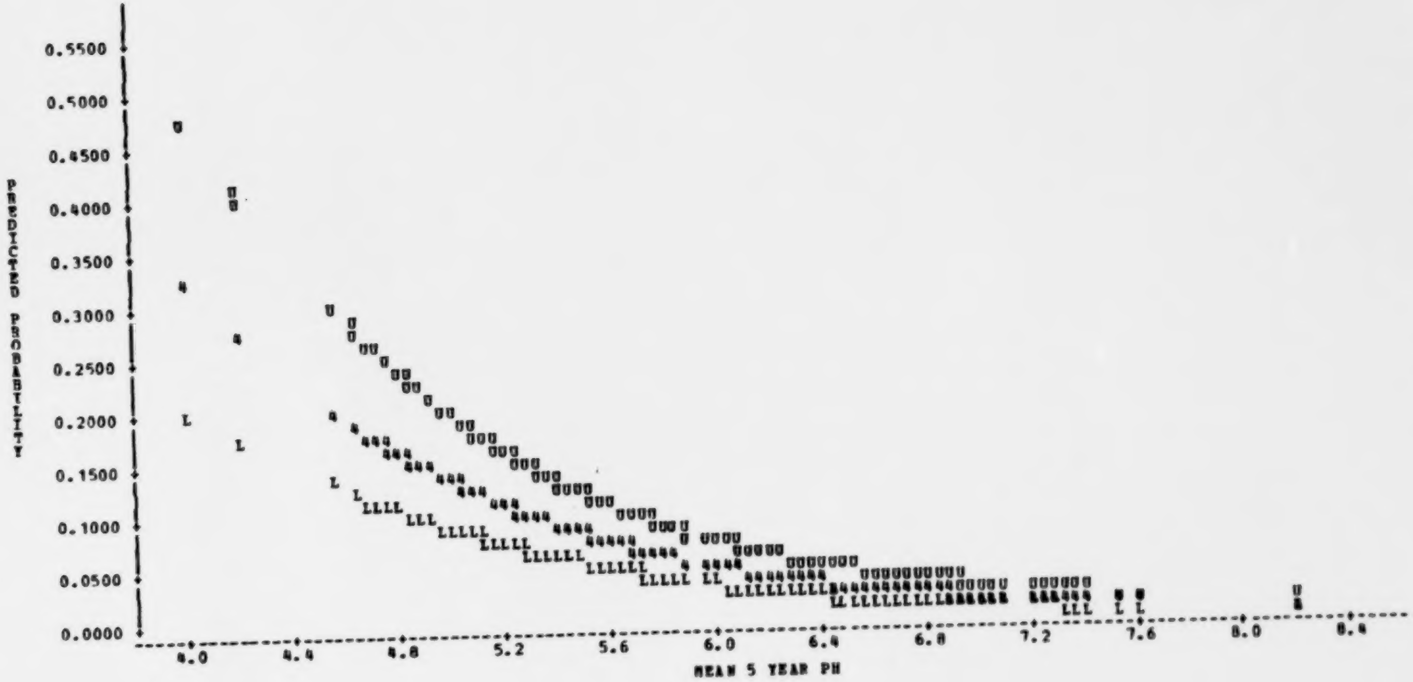

Figure 62. Predicted probability (and 95% confidence interval: U to L) that fish community status ≥ 4, as a function of mean 5-year pH.

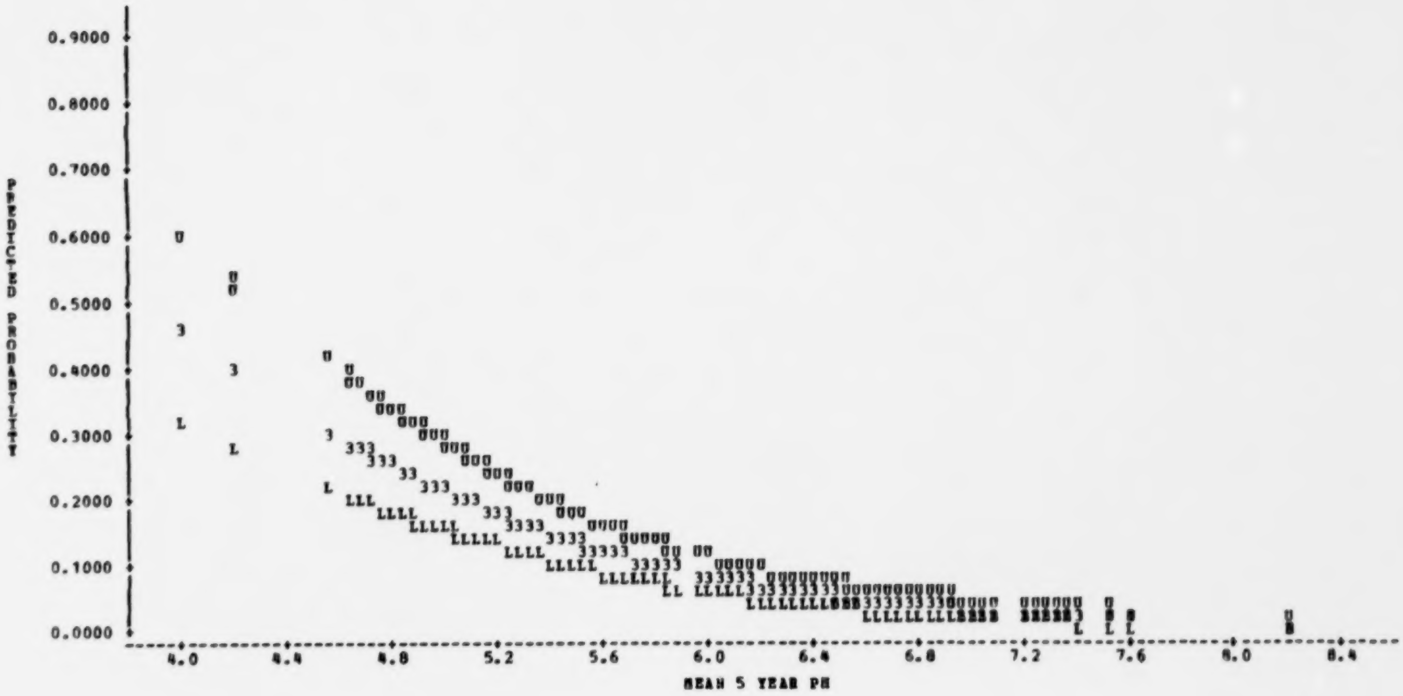

Figure 63. Predicted probability (and 95% confidence interval: U to L) that fish community status ≥ 3, as a function of mean 5-year pH.

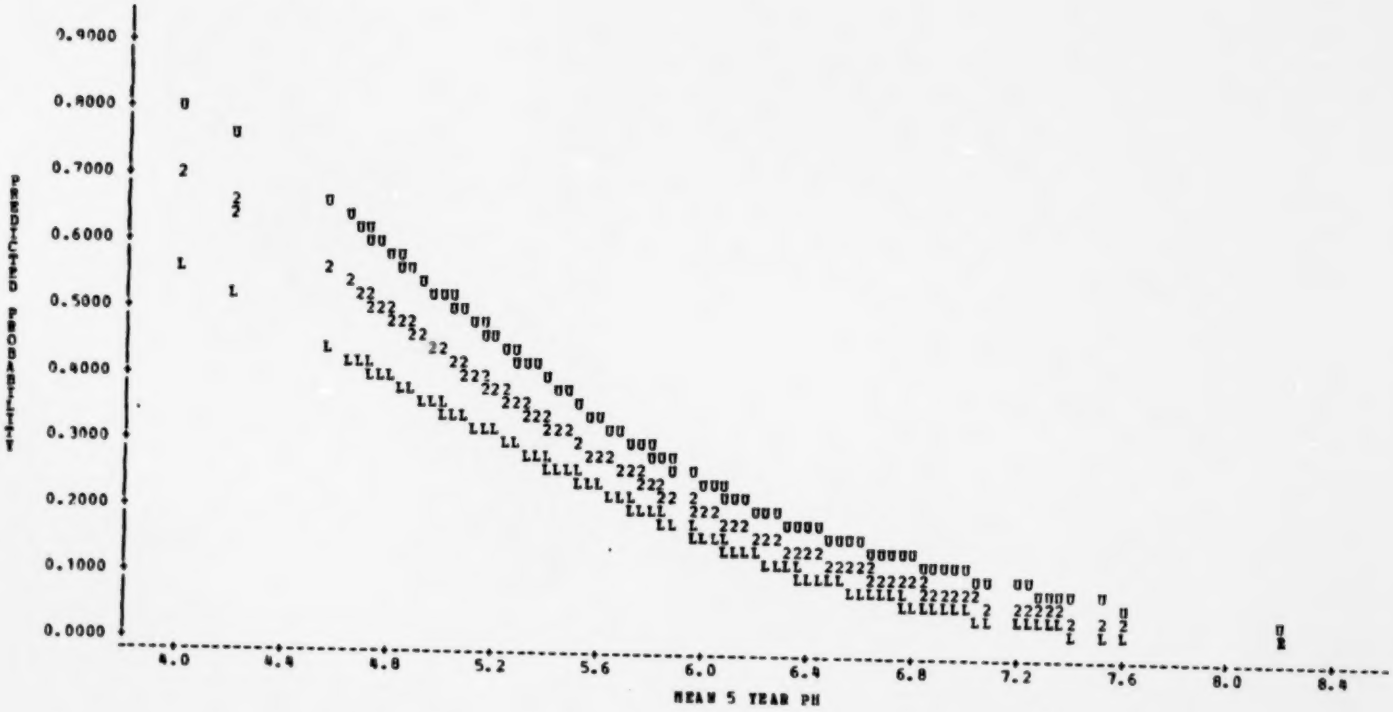

Figure 64. Predicted probability (and 95% confidence interval: U to L) that fish community status ≥ 2, as a function of mean 5-year pH.

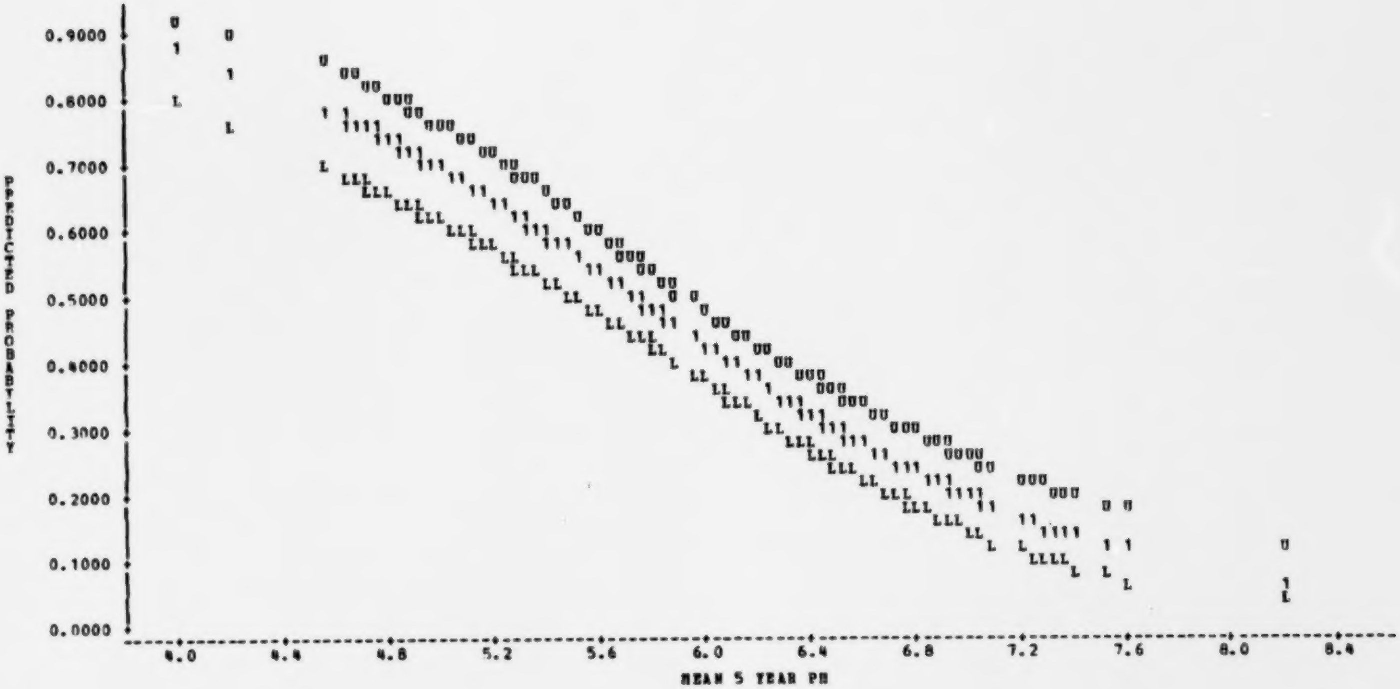

Figure 65. Predicted probability (and 95% confidence interval: U to L) that fish community status ≥ 1, as a function of mean 5-year pH.

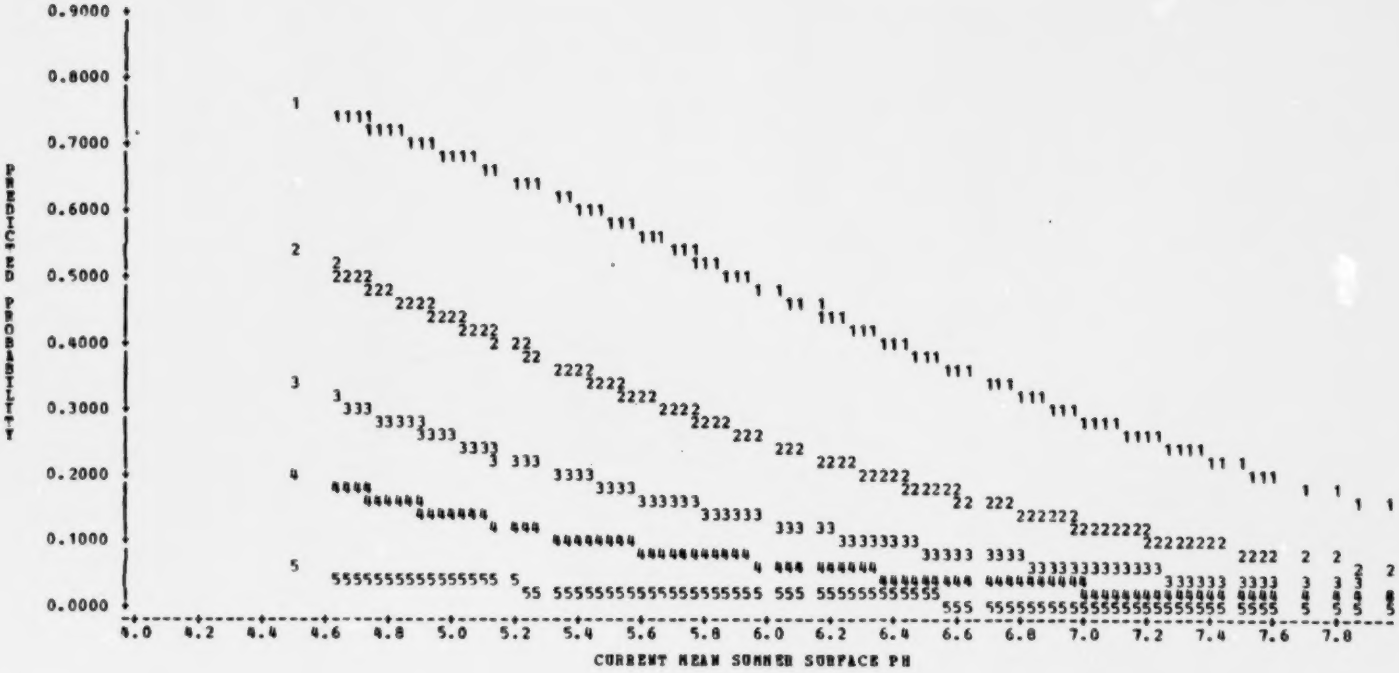

Figure 66. Predicted probability that fish community status $\geq$ s (for s 1 to 5) as a function of current (1974-1983) mean summer surface pH (electrometric, air-equilibrated).

Variable	Beta	Std. Error	Chi-Square	P
Intercept1	4.91	1.00	24.05	0.0000
Intercept2	3.89	0.98	15.68	0.0001
Intercept3	3.06	0.97	10.00	0.0016
Intercept4	2.34	0.97	5.83	0.0158
Intercept5	0.84	1.05	0.64	0.4241
pH	-0.83	0.16	25.84	0.0000

The rank correlation between predicted probability and response = 0.340

$r = 0.216$
total observations = 216

9. DOES THE PRESENCE OF HIGH CONCENTRATIONS OF DISSOLVED ORGANICS MODIFY THE RELATIONSHIP BETWEEN FISH COMMUNITY STATUS AND LAKE pH?

The toxic effects of acidic waters result not only from high concentrations of H^+ ions but also from elevated concentrations of inorganic aluminum (Schofield and Trojnar 1980, Driscoll et al. 1980, Baker and Schofield 1982). Complexation of aluminum with organic ligands reduced or eliminated aluminum toxicity in laboratory bioassays (Driscoll et al. 1980, Baker 1981). Thus, the presence of high concentrations of dissolved organics in natural waters may mitigate the adverse effects of acidification by reducing the potential for aluminum toxicity. If this ameliorating effect is significant we would expect to reject the null hypothesis:

H_0: The relationship between fish community status and lake pH is identical in clear-waters (visual color < 1.5), presumably with low concentrations of dissolved organics, and in waters classified as light brown or brown (visual color ≥ 2.5), indicative of high concentrations of dissolved organics

for the alternate hypothesis:

H_1: Fish communities are adversely affected at higher pH levels in clear-waters (visual color < 1.5) than in waters classified as light brown or brown (visual color > 2.5).

Numbers of lakes with clear (visual color < 1.5) and highly colored waters (visual color > 2.5) with fish community status classified as 0 or 1, or 3, 4, or 5 are summarized in Table 6 by pH intervals. Inclusion of visual water color (as a binary independent variable) in the logistic models predicting fish community status is significant at $p < 0.05$, even after adjusting for differences due to lake pH. Defining color = 0 for clear-water lakes with visual color < 1.5 and color = 1 for light brown and brown water lakes (visual color ≥ 2.5), the logistic regression model coefficients for predicting status, the binary dependent variable defined in the previous section, are (Figures 67-68):

Table 6. Numbers and proportion of lakes in each pH interval for clear-water lakes (visual color < 1.5) and lakes classified as light brown or brown (visual color > 2.5) with fish community status rated 3, 4, or 5.

	Total Number of Lakes		Fish Community status = 3, 4, or 5	
	Visual color		Visual color	
pH	<1.5	> 2.5	< 1.5	> 2.5
< 5.0	7	15	.86	.33
5.0 - 5.5	14	19	.57	.16
5.5 - 6.0	21	23	.09	.04
6.0 - 6.5	18	39	.06	0
6.5 - 7.0	16	36	0	0
7.0 - 7.5	7	12	0	0
7.5 - 8.0	2	2	0	0
8.0 - 8.5	0	1	-	0

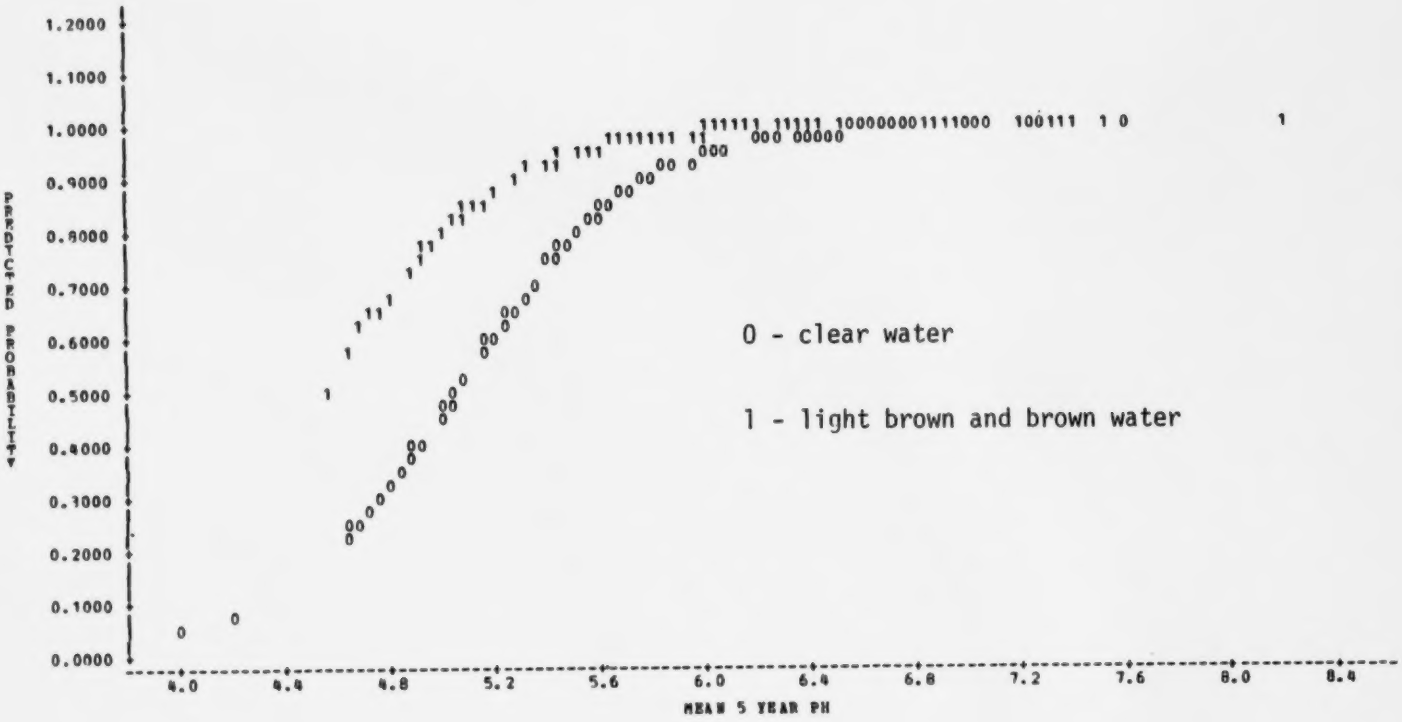

Figure 67. Predicted probability that status = 1 (fish community 'healthy') as a function of mean 5-year pH, for lakes classified as clear water (visual color < 1.5) and light brown or brown water (visual color > 2.5).

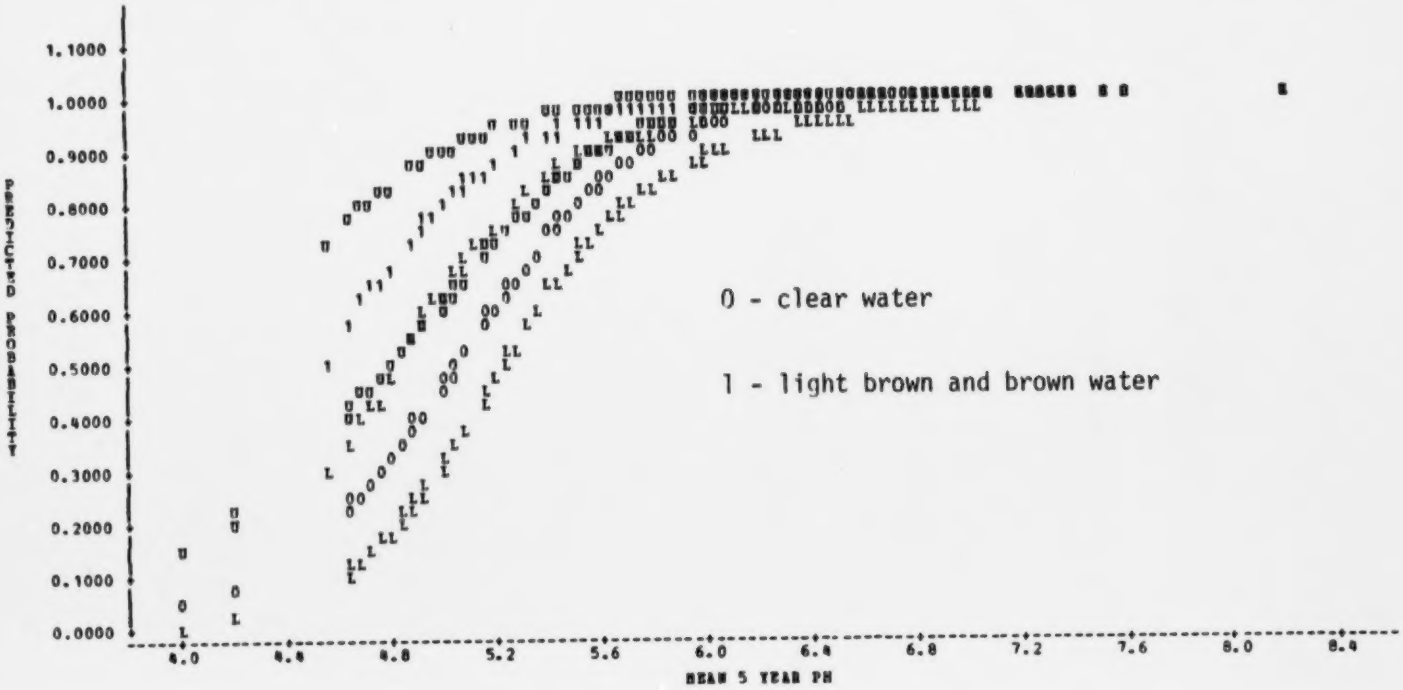

Figure 68. Predicted probability (and 95% confidence intervals: U to L) that status = 1 (fish community 'healthy') as a function of mean 5-year pH for lakes classified as clear water (visual color < 1.5) and light brown or brown water (visual color > 2.5).

Variable	Beta	Std. Error	Chi-Square	P
Intercept	-15.00	2.57	34.17	0.0000
pH	2.97	0.48	38.87	0.0000
Color	1.50	0.49	9.24	0.0024

The rank correlation between predicted probability and response = 0.843

r = 0.611
n = 295 for status = 1
n = 35 for status = 0

For the logistic model predicting the ranking of fish community status (0 to 5) (Figure 69), the estimated model coefficients are:

Variable	Beta	Std. Error	Chi-Square	P
Intercept1	6.30	0.91	48.16	0.0000
Intercept2	5.25	0.89	34.76	0.0000
Intercept3	4.17	0.87	22.77	0.0000
Intercept4	3.67	0.87	17.58	0.0000
Intercept5	2.51	0.91	7.59	0.0059
pH	-1.07	0.15	51.44	0.0000
Color	-0.51	0.22	5.53	0.0187

The rank correlation between predicted probability and response = 0.372

r = 0.253
total observations = 373

In both models, at a given pH the predicted probability that the fish community is 'healthy' (i.e. fish community status rating 0 or 1) is significantly higher in the light brown/brown waters (visual color > 2.5) than in clear-water lakes (visual color < 1.5).

Thus, it appears that fish communities can 'tolerate' lower pH levels in highly colored waters than in clear-water lakes, presumably with low concentrations of dissolved organics. Alternatively, however, fish species that tend to occur in light brown/brown-water lakes may be more tolerant of acidic conditions than are fish species that occur in clear-water lakes. Analyses based solely on the fish community status rating cannot distinguish between these two competing hypotheses. Similar analyses for individual fish species are presented in Section 13.

10. HOW MANY FISH COMMUNITIES HAVE BEEN ADVERSELY AFFECTED BY ACIDIFICATION IN THE ADIRONDACKS?

The above analyses support the premise that the ratings of fish community status on an ordinal scale 0 to 5 reasonably represent the adverse effects of acidification on fish communities. Of the 604 lakes with adequate survey data for classification of fish community status, 358 (59%) were rated as zero, 133 (22%) as one, 64 (11%) as two, 23 (4%) as three, 18 (3%) as four, and 8 lakes (1%) as five (Figure 42).

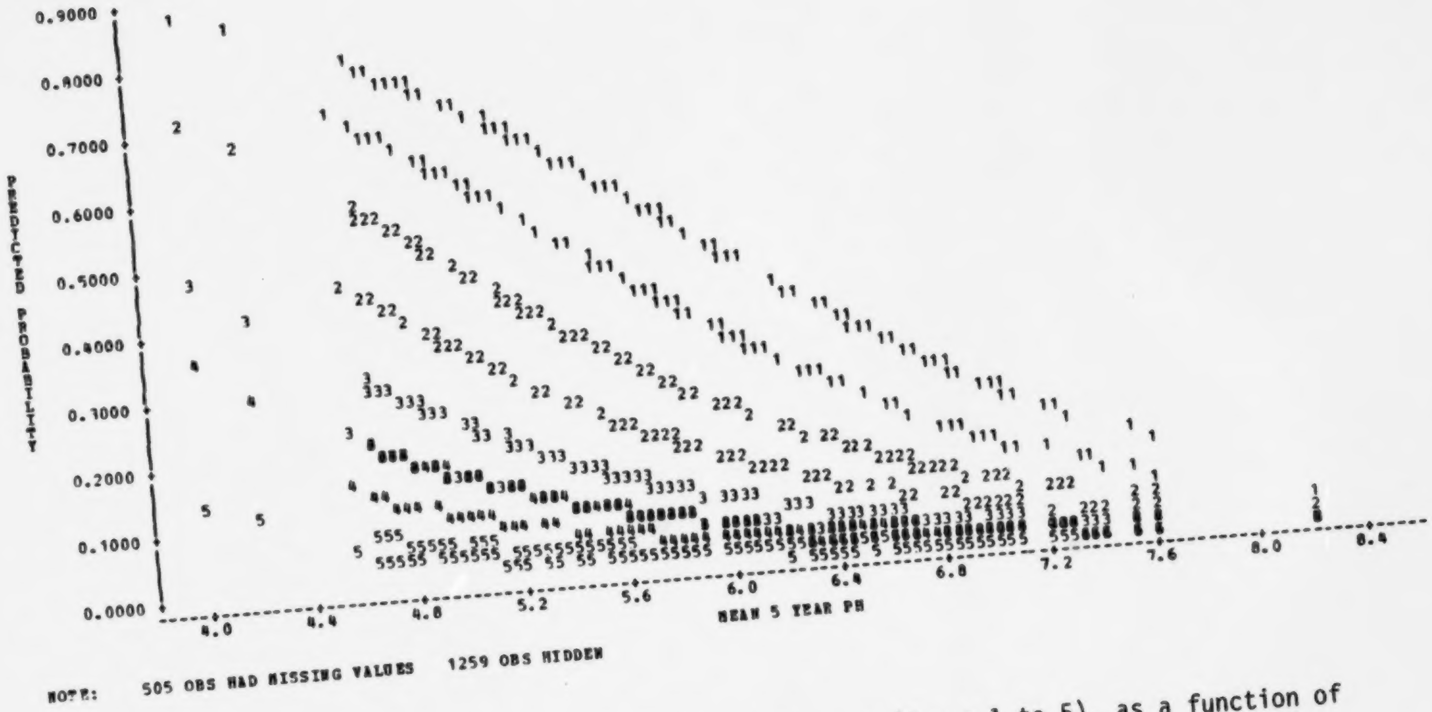

Figure 69. Predicted probability that fish community status $\geq$ s (for s 1 to 5), as a function of mean 5-year pH, for lakes classified as clear water (visual color < 1.5) and light brown or brown water (visual color > 2.5). For a given rating of fish community status, at a given pH, the predicted probability for clear-water lakes is greater than the predicted probability for light brown/brown-water lakes.

Several problems have to be considered, however, in interpreting the numbers of lakes in each class of fish community status. First, where exactly on the scale of 0 to 5 do we define "communities adversely affected by acidification"? For the 49 lakes (8.1%) with fish community status rated 3, 4, or 5, many, and in some lakes, all fish populations had been lost, apparently as a result of acidification. It seems reasonable that at the least these should be considered 'adversely affected'. Sixty-four lakes (10.6%) received a fish community status rating of 2, indicative of loss or decline of one or several species, but no drastic demise of the community. Fish communities in these lakes were less severely impacted, and the evidence that any changes resulted from acidification was less clear. Should some or all of these lakes also be included in counting the number of fish communities 'adversely affected'? We suspect that many should be, but do not presume to know what fraction of the 64 lakes to include. So far, therefore, the count ranges from 49 to 113.

10.1. Errors in Classification of Fish Community Status

What about problems with misclassification? Some fish communities rated as 'healthy' (0 or 1) in actuality may have been adversely affected (3, 4, or 5), and vice versa. Misclassification, in addition to errors in pH measurements and natural variations in sensitivities of fish communities to low pH, contribute to the range of lake pH levels observed for the two classes of status ('healthy' vs. clearly impacted) in Figure 49. Three lakes with pH 6.0 to 6.5 (two of these were brook trout lakes) had fish community status rated as $\geq$ 3. It is unlikely at pH levels this high that most or all fish populations were lost as a result of acidification. These are probably examples of error, most likely in the classification of fish community status but perhaps in the measurement of pH.

Likewise, there are probably lakes with fish community status rated 0 or 1 that have actually been adversely affected. For fish communities rated 1 (133, 22%) survey data suggested that one to several species had declined or been lost over time, but apparently as a result of natural fluctuations in community composition or catchability rather than acidification. The potential influence of acidification could not, however, be positively ruled out. Field surveys of fish populations are very inexact. Declines in fish abundance over time, as a result of partial or complete reproductive failure, are difficult to impossible to detect. Major changes in the status of the population or fish community would have to have occurred prior to detection of change based on the available data and classification of fish community status $\geq$ 3. If the error rates are approximately equal in the two groups of lakes, 'healthy' vs 'adversely affected', a greater number of lakes (almost 10 times as many) would have been misclassified as 'healthy' than misclassified as 'adversely affected,' because of the greater number of lakes classified as 'healthy' (0 or 1).

Unfortunately these classification errors cannot be quantified. We have no sample of lakes of known status with which to compare our ratings of fish community status. Estimates of variance associated with rating fish community status, either by a single individual or among a group of independent investigators, are quite distinct from true error rates. Even for the 604 lakes with adequate fish survey data we will never know the answer to how many fish communities have been adversely affected by acidification. The answer varies with the definitions of 'adequate data' and 'adequate evidence'.

10.2. Limitations of the Available Data

Several points also need to be made concerning the representativeness of our sample of 604 lakes with 'adequate data', both with regard to the definition of adequate and the types of lakes likely to have adequate data for detection of trends. We wished to rate the status of fish communities for as many lakes as possible to evaluate the relationship between the rating and lake pH and changes in pH over time. Determination that a fish community in a lake appeared 'healthy' generally required fewer, less intensive samples than detection of decline or loss of populations over time. Lakes with a diversity of species considered typical for that habitat type were rated 'healthy' even if data were available only from a single, recent survey of fish populations. On the other hand, lakes sampled only once or twice, and only fairly recently, lacking fish or missing species considered typical of that habitat type have been excluded from the 604 lakes with 'adequate' data for detection of trends.

For example, 30 lakes stocked with brook trout in at least the year immediately preceeding the survey (and often for many years preceeding the survey) were surveyed once and no fish were caught. Twenty-four of these lakes had pH data available for the 5-year period centered on the year of the fish survey. pH ranged from 4.6 to 6.8, with an overall mean of 5.11 (Figure 70):

$$P\ (4.89 \leq \mu \leq 5.33) = 0.95$$

Comparing these pH values with those for lakes with fish community status rated ≥ 3 (Figures 43 and 49) suggests that for many of these lakes the failure of brook trout stocking and the absence of other fish species may have resulted from high levels of acidity. Factors other than acidity also, however, may result in stocking failure and the absence of fish. Because of the lack of survey data indicating changes through time, we have not included these lakes in analyses based on fish community status nor in counts of numbers of fish communities adversely affected by acidification. If all or some of these lakes did in the past support fish then our count of fish communities adversely affected would range from 49 (only lakes with fish community status ≥ 3) to 113 (status ≥ 2) to 143 (including lakes with only recent survey data but apparent stocking failure).

Eighty-eight additional lakes have only recent survey data and no fish (or only brown bullhead) were caught (but were not stocked with brook trout immediately prior to the survey). All of these were fairly small lakes, at higher elevations, and would typically be considered brook trout waters. Eighty of these lakes have pH data available for the 5-year period centered on the year of the fish survey. pH ranged from 4.0 to 7.0 (Figure 71) and averaged 5.16:

$$P\ (5.00 \leq \mu \leq 5.31) = 0.95$$

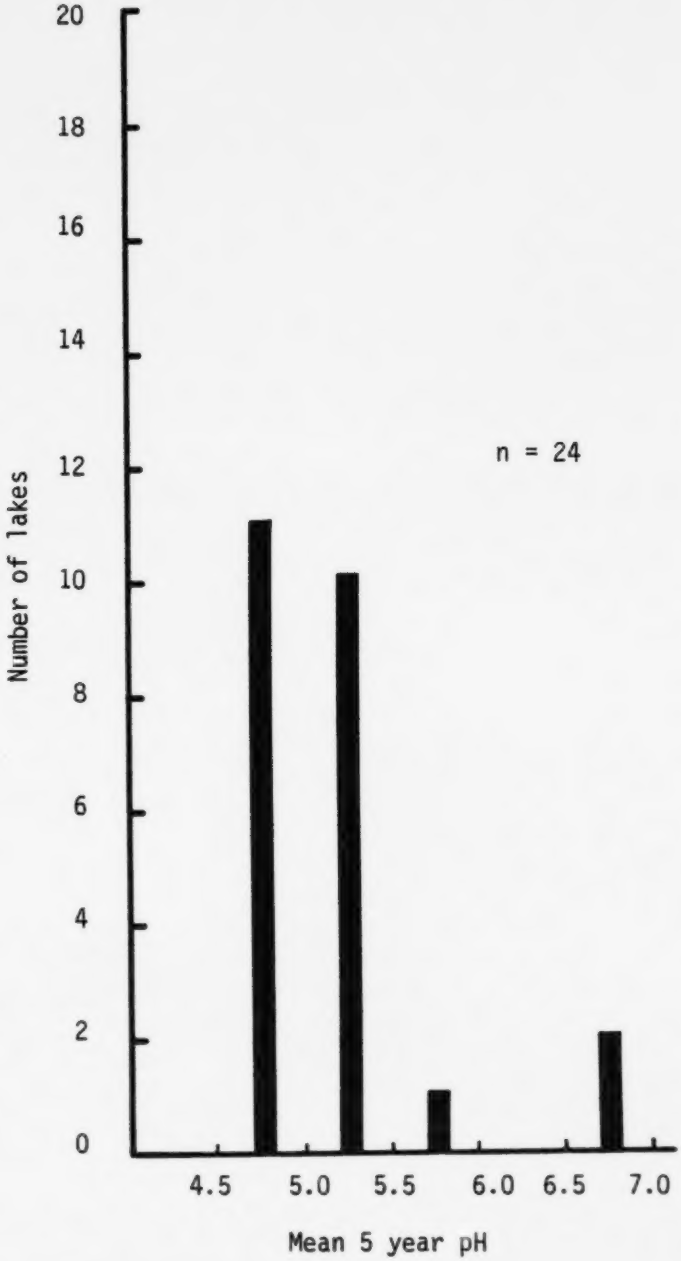

Figure 70. Frequency distribution of mean 5-year pH for lakes with only recent survey data and brook trout stocking failure.

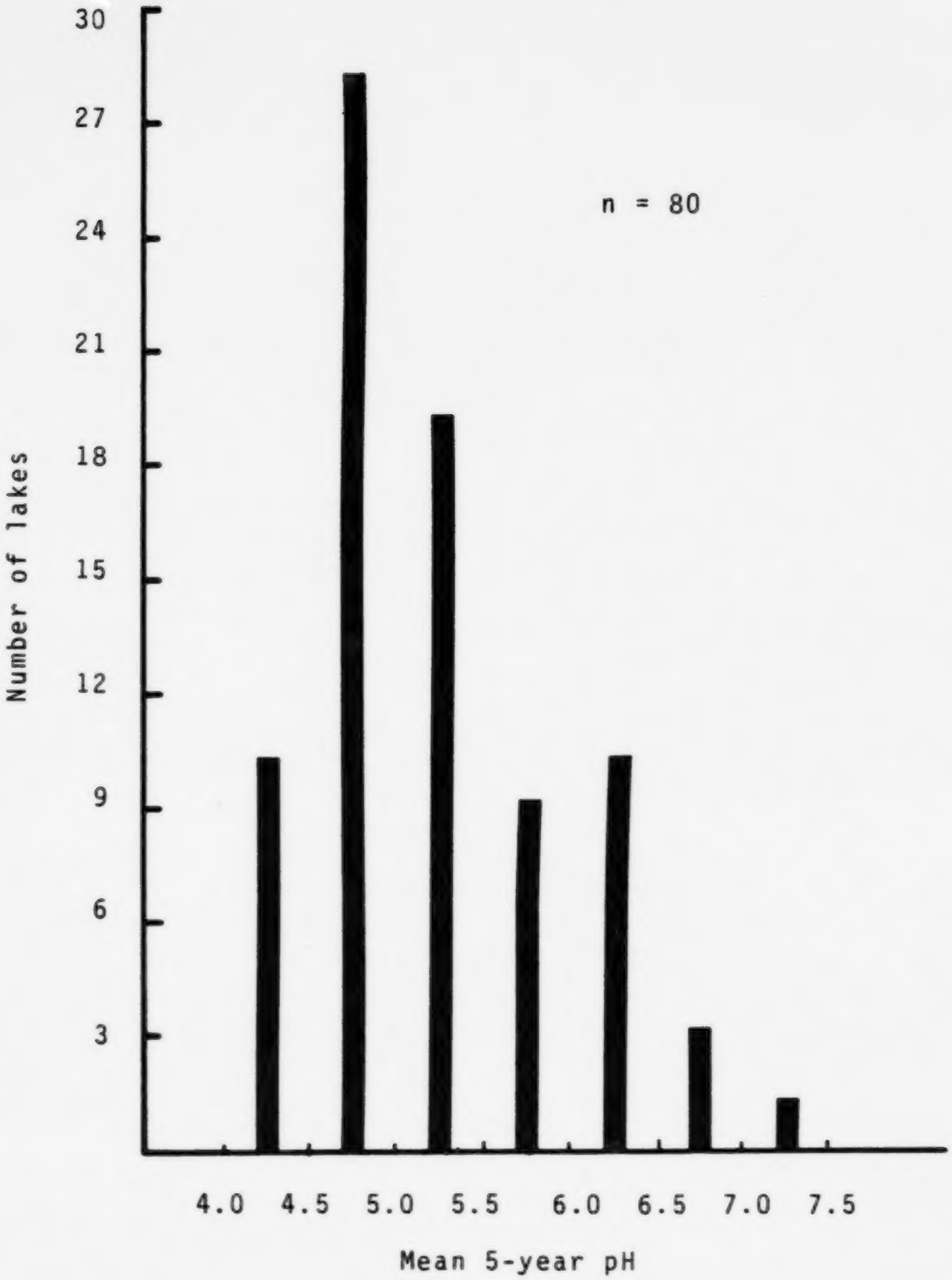

Figure 71. Frequency distribution of mean 5-year pH for lakes with only recent survey data and no fish caught.

Again, comparing these pH levels with those for lakes with fish community status rated $\geq$ 3 (Figures 43 and 49) suggests that fish communities in these lakes (in the past) may have been adversely affected by acidification. We cannot, however, determine what fraction of these lakes actually had fish populations in earlier years. Seventeen of these lakes (mean pH 5.56) were noted (in written comments by field biologists) as unsuitable for trout for reasons other than acidity. If all or some of the 71 lakes with no obvious explanation for the lack of fish (other than perhaps acidity) actually supported fish populations in the past then our count of numbers of fish communities adversely affected by acidification would range from 49 (status $\geq$ 3) to 113 (status $\geq$ 2) to 143 (stocking failure) to 231 (including lakes with only recent survey data and no fish caught).

Thirty-one lakes have only recent survey data and only brook trout and/or brown bullhead were caught. Both of these species are considered relatively tolerant of low pH. It is possible that these lakes in the past supported additional species typical of this habitat type, e.g., white sucker, pumpkinseed sunfish, and creek chub. Many brook trout waters, however, contain only brook trout, independent of any pH effects. Thus, we have no evidence for loss of other species over time. At the same time data were not sufficient to classify these brook trout only, or brook trout and brown bullhead fish communities as 'healthy'. Twenty-three of these lakes have pH values for the 5-year period centered on the year of the fish survey. Values range from 4.35 to 7.50, and averaged 5.70 (Figure 72):

$$P\ (5.31 \leq \mu < 6.09) = 0.95$$

It is unlikely that all of these lakes had fish communities adversely affected by acidification. At the maximum it would increase our count of numbers of fish communities adversely affected by 31, to 262.

The effect of the differential data requirements for classifying fish communities as apparently 'healthy' as compared to 'adversely affected' can also be evaluated in part by examining the relationship between the percent of fish communities classified as 'adversely affected' (rated 3, 4, or 5) and quantity of survey data available. Of the original 604 lakes, 49 (8.1%) had fish community status rated as $\geq$ 3. Requiring a minimum of three fish surveys in separate years over a period of at least 10 years for classification of fish community status, the number of lakes with adequate data decreases to 289, but 10.7% of these (31 lakes) had fish community status rated $\geq$ 3.

10.3. Potential Bias in Selection of Lakes Surveyed

Restrictions on the minimum number of surveys needed for evaluation of fish community status, however, introduce a second potentially more serious bias. Lakes surveyed for fish were not selected at random. Prior to 1970, in particular, surveys concentrated on readily accessible waters with productive fisheries or fisheries management problems. As a group these lakes are likely to be less susceptible to acidic deposition, and fish communities in these lakes are less likely to have been adversely affected by acidification. In recent years, the DEC has recognized the need for

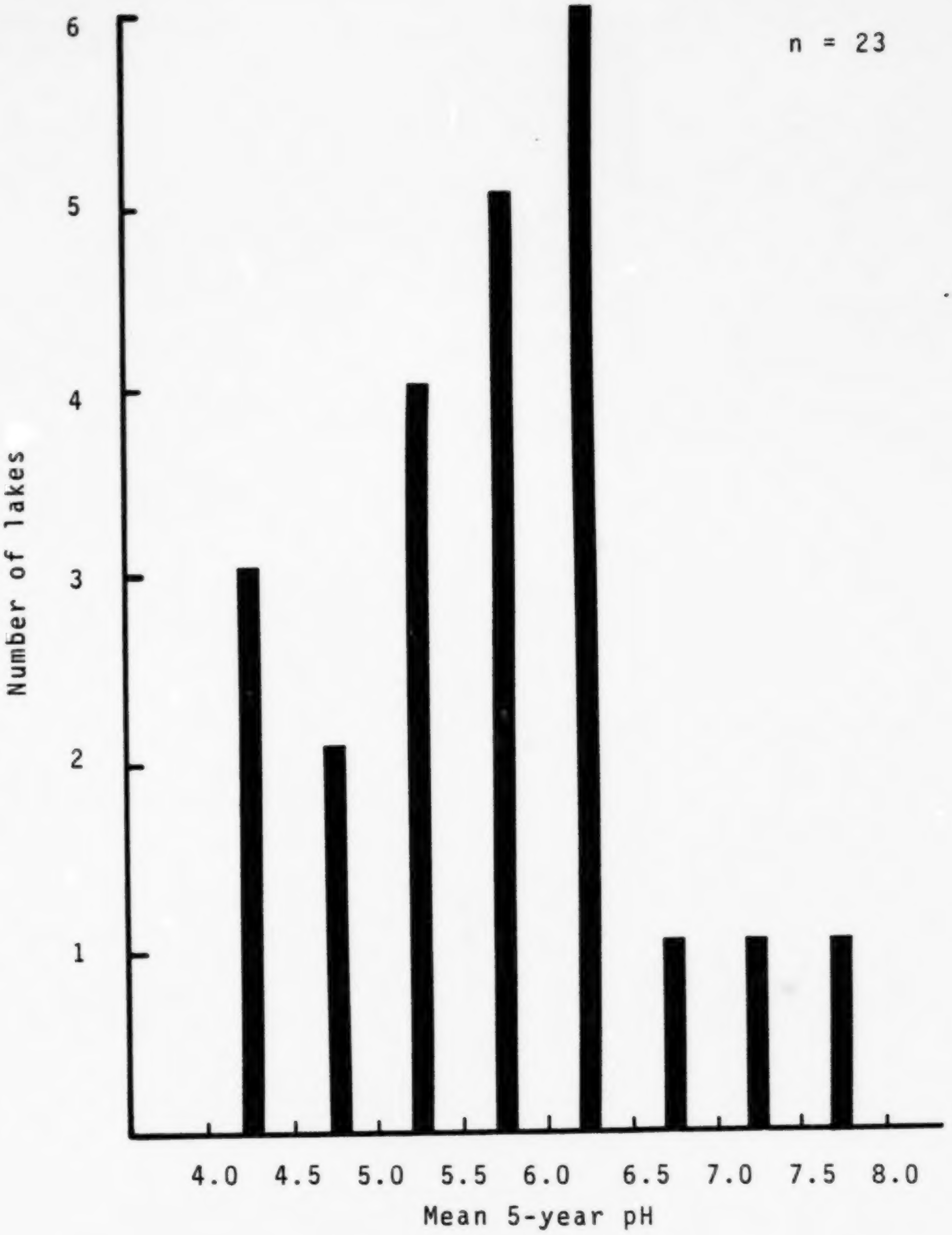

Figure 72. Frequency distribution of mean 5 year pH for lakes with only recent survey data and only brook trout and/or brown bullhead caught.

more information on waters potentially impacted by acidic deposition. Recent surveys have been biased towards lakes most likely to be sensitive and/or already impacted. Assessment of declines in fish populations over time, however, requires some historical survey data. Thus our sample of lakes with 'adequate' data for assessment of trends through time is likely to be biased towards larger lakes, at lower elevations, and with higher pH levels. The magnitude of this bias is demonstrated in Table 7 and Figures 73 to 75. Smaller lakes with lower pH (< 5.0) in particular are under-represented in our subset of lakes with adequate fish survey data for classification of fish community status.

Table 7. Lake area, elevation, and pH for lakes in the Adirondacks, lakes with current (1974-1983) pH data, and lakes surveyed for fish.

	Geometric Average Area (ha)	Average Elevation (m)	Average pH 1974-1983
Lakes in Adirondacks	5.5	499	-
Lakes with current (1974-1983) pH data	13.6	557	6.02
Lakes with fish community status defined	18.3	499	6.24
Lakes surveyed for fish 3 or more times over 10 or more years	27.2	510	6.15

approximately 18% for the 693 lakes with current pH values:

$$P\ (14.5\% \leq \mu \leq 21.3\%) = 0.95$$

We would like to use our sample of 604 lakes to estimate fish community status for all 2759 lakes in the Adirondack Ecological Zone. Unfortunately our understanding of the biases associated with our subset of 604 lakes is inadequate, and any extrapolations potentially inaccurate. For example, if we assume that the distribution of lake pH values illustrated in Figure 13 reasonably represents the distribution of lake pH for all Adirondacks lakes (refer to Section 2), then we could stratify our subset of lakes with fish data by lake pH and correct for associated biases. Using current summer surface pH values and data for the 321 lakes with both fish community status and current pH values (Figure 75), the estimated percentage of lakes with fish community status rated 3, 4, or 5 would increase from 8.1%, observed in the sample of 604 lakes, to Alternately, using 5-year mean pH values (Figure 76) and data for the 396 lakes with both 5-year mean pH and fish community status defined, the estimated percentage of fish communities rated 3,4 or 5 is 14%:

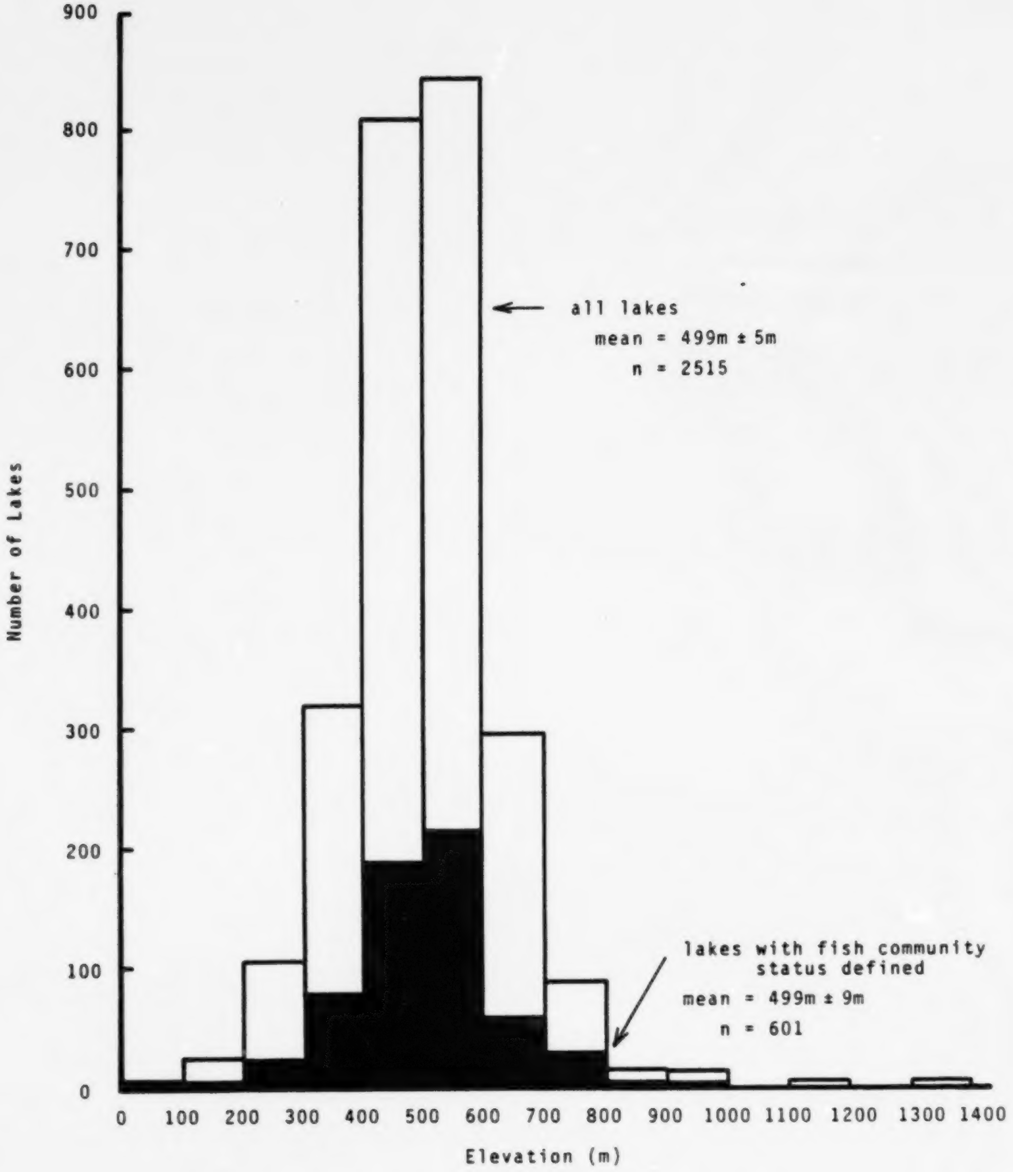

Figure 73. Frequency distribution of lake elevation.

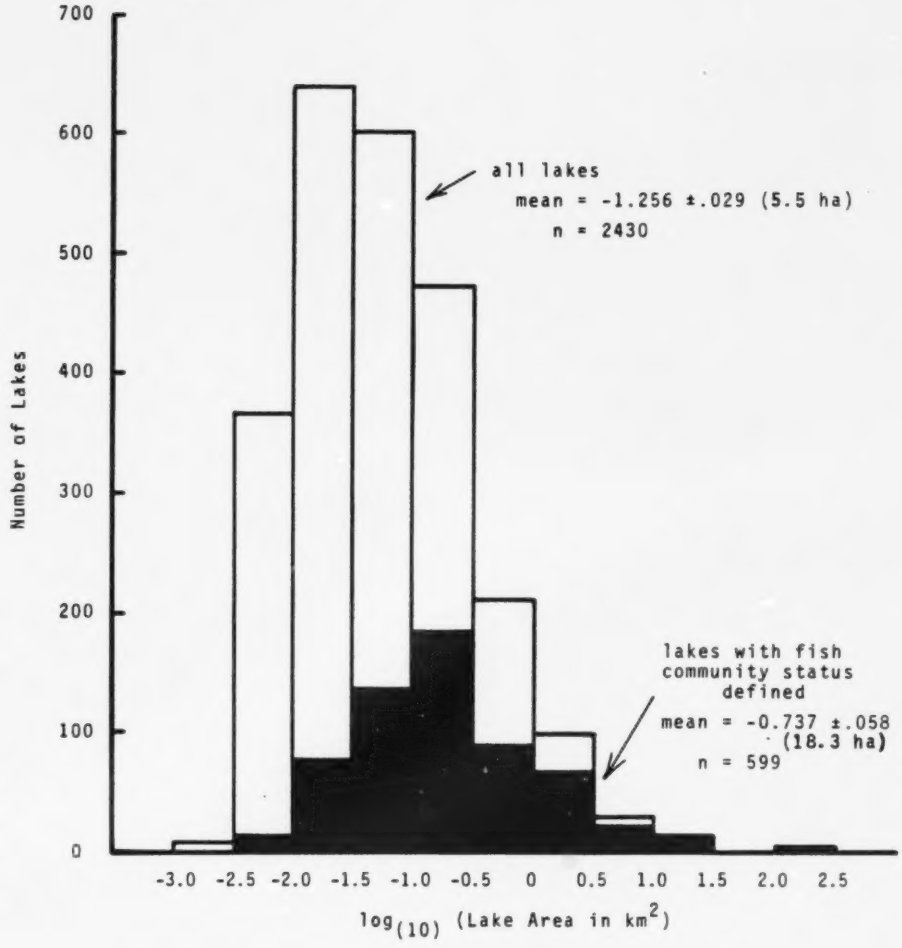

Figure 74. Frequency distribution of lake area.

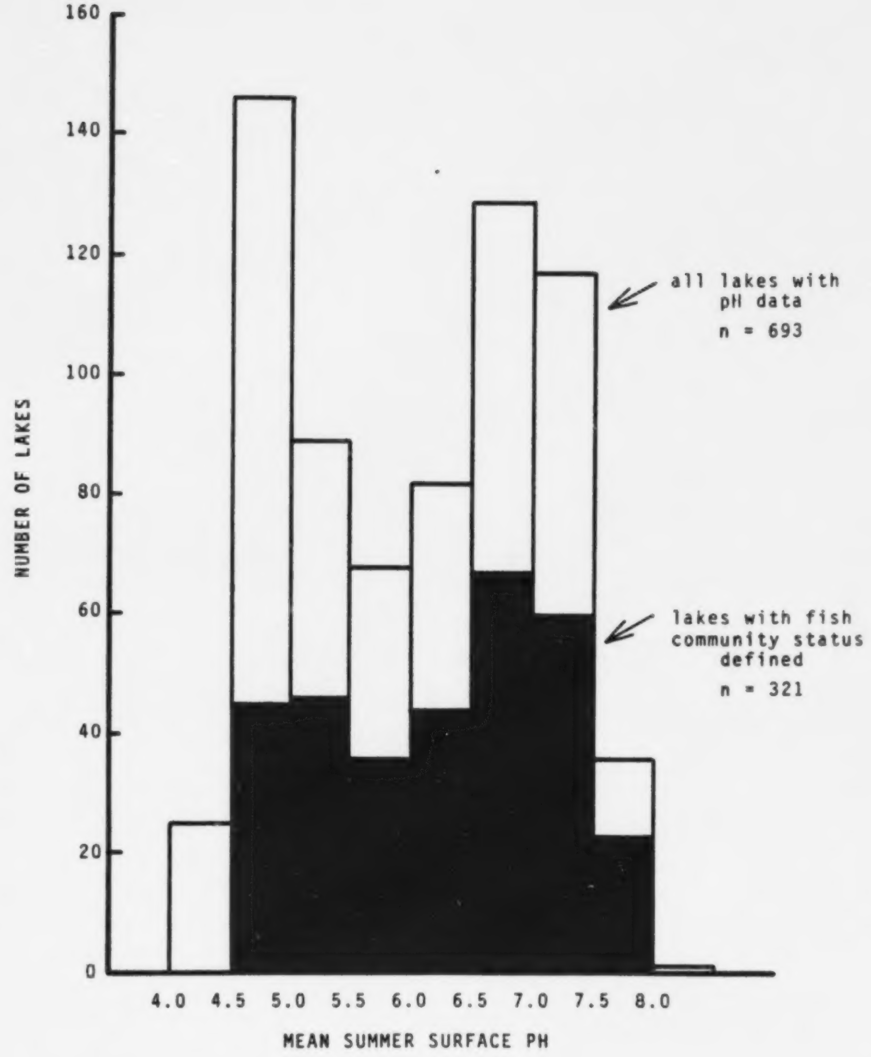

Figure 75. Frequency distribution of current (1974-1983) summer surface pH (electrometric, air-equilibrated).

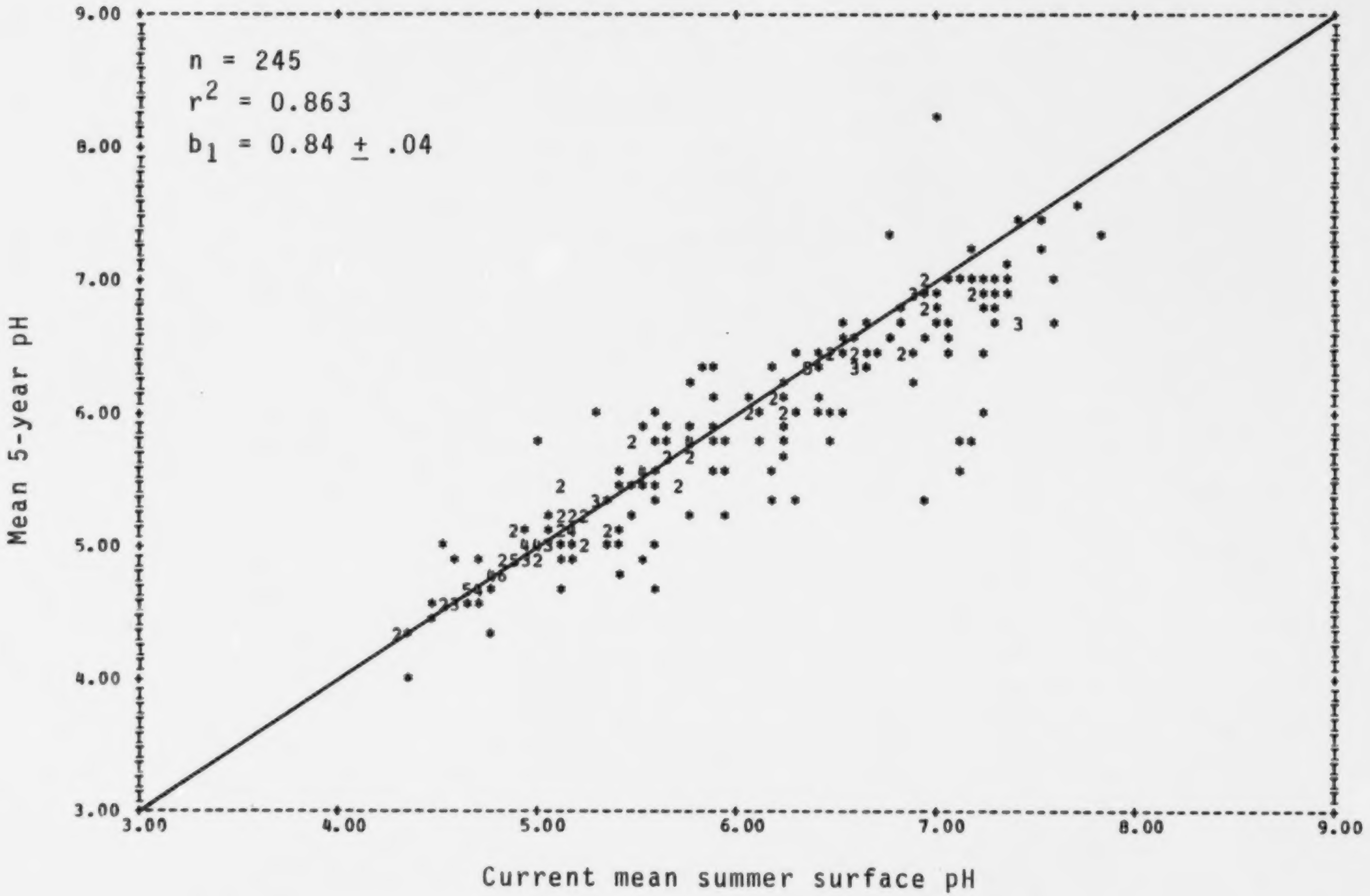

Figure 76. Mean 5 year pH (all pH methodologies) (for 1974-1983) plotted as a function of the current (1974-1983) mean summer surface pH (laboratory electrometric, air-equilibrated).

$$P\ (10.5\% \leq \mu \leq 17.7\%) = 0.95$$

Restricting the sample to lakes sampled 3 or more times over 10 or more years, the estimate increases to 16%:

$$P\ (11.5\% \leq \mu \leq 20.6\%) = 0.95$$

All of these calculations, however, assume that for a given pH interval the sample accurately reflects the distribution of fish community status for all lakes in that pH interval. We know, however, that fish surveys, particularly those prior to 1970, were biased towards lakes of interest to fisheries managers, i.e., lakes with fish. Some fraction of Adirondack lakes never supported fish communities and never will, for reasons unrelated to acidity status. The number of lakes in this category is unknown, but for the most part they are principally smaller, shallower lakes at higher elevations. Such lakes are also more likely to be acidic, and more likely to have been classified as having fish community status $\geq$ 3 in the above extrapolations. As a result, estimates of the number of fish communities adversely affected by acidification would be too high by an unknown amount. On the other hand, the above estimates are based upon fairly stringent criteria for defining a fish community as adversely affected (i.e., fish community status $\geq$ 3; no lakes with fish community status rated 2 have been included).

10.4. Summary

How many fish communities in the Adirondacks have been adversely affected by acidification? We will never know for sure. We feel confident that the number is at least 50. Depending upon how restrictive your definition of sufficient evidence, we have survey data that indicate as many as 200 to 250 have been measurably impacted (loss of one or more populations). For Adirondack lakes in general perhaps up to 400 to 500 (14-18%) have been adversely affected. It should be clear, however, that these are fairly rough estimates, and the associated levels of uncertainty cannot be quantified.

11. IS THERE EVIDENCE THAT FISH POPULATIONS HAVE BEEN LOST FROM ADIRONDACK LAKES AS A RESULT OF ACIDIFICATION?

In addition to evaluating the status of the fish community as a whole, shifts in abundance through time and possible explanations for these changes were evaluated for individual populations of fish in Adirondack lakes. Evaluation at the population level, however, proved to be much more difficult. As a result of inefficiencies in sampling and factors other than acidity influencing population status, marked fluctuations in the abundance of individual fish species (including total absence from the catch) were not uncommon. In many cases, we were unable to definitively separate the effects of acidification from this "background noise". As a result, the variance associated with assessing the status of individual populations, with regard to potential effects of acidification, was greater than the variance associated with assessment of fish community status.

For each of the 14 fish species considered, we have attempted to address questions similar to those noted above for fish community status; (1) Is there evidence of adverse effects? (2) How many populations have been lost or declined?, and (3) What is the relationship between fish population status and pH and water color? These discussions will be fairly brief. The problems and limitations for each of these analyses are similar to those encountered in analyses of fish community status; discussion of these issues will not be repeated here.

For each species occurring (or that once occurred) in a given lake, three confidence ratings were assigned (refer to more detailed discussion in Section III), on an ordinal scale from 0 (low) to 9 (high); the evaluator's confidence that: (1) the population has remained constant or increased in abundance over time, (2) the population has declined (decreased abundance, reproductive failure, and/or total extinction) over time, and (3) the population has been lost. For populations rated > 0 for population decline and/or loss, a fourth confidence rating was also provided: on an ordinal scale 0 (low) to 9 (high), the likelihood that the population decline and/or loss resulted from acidification. As with the fish community status rating, a high value for likely adverse effects due to acidification actually reflects a lack of evidence for alternate explanations for the observed decline/loss (e.g., change in stocking policy, reclamation, community interactions, etc.). All four evaluations of population status were completed with no information on lake identity or specific locale, and no information on water chemistry or acidity status.

Since fish populations fluctuate in abundance for many reasons other than acidification, we would not expect ratings for population decline or loss to be clearly correlated with lake pH or changes in pH over time (e.g., Figures 77 and 78). Thus, the principal variable used to distinguish adverse effects of acidification is the fourth rating: the likelihood that the population decline/loss resulted from acidification. Criteria for rating populations with regard to the likelihood of adverse effects due to acidification were summarized in Section III. In brief, ratings of 0 to 4 indicate changes probably due to causes other than acidification. A rating of 5 was considered marginal, i.e., some suggestion that the decline may be due to acidification but no clear trends. Populations rated 6 and above were considered likely to have been affected by acidification, with the increasing rating 6 to 9 generally reflecting increasing confidence in the assessment of the role of acidification in observed population declines and/or loss.

Evidence that acidification has resulted in the loss of some fish populations in the Adirondacks therefore consists of two components: (1) evidence that these ratings of fish population status are doing what they were designed to do, i.e., a statistically significant correlation between population rating and lake pH and/or changes in pH over time, and (2) for each species of interest, some populations that received ratings indicative of effects due to acidification. Again, we recognize that a significant correlation between population ratings and chemical variables indicative of acidification and/or acidity status does not, in itself, prove cause-and-effect. It does, however, add credence to the argument that fisheries declines have occurred in the Adirondacks as a result of acidification.

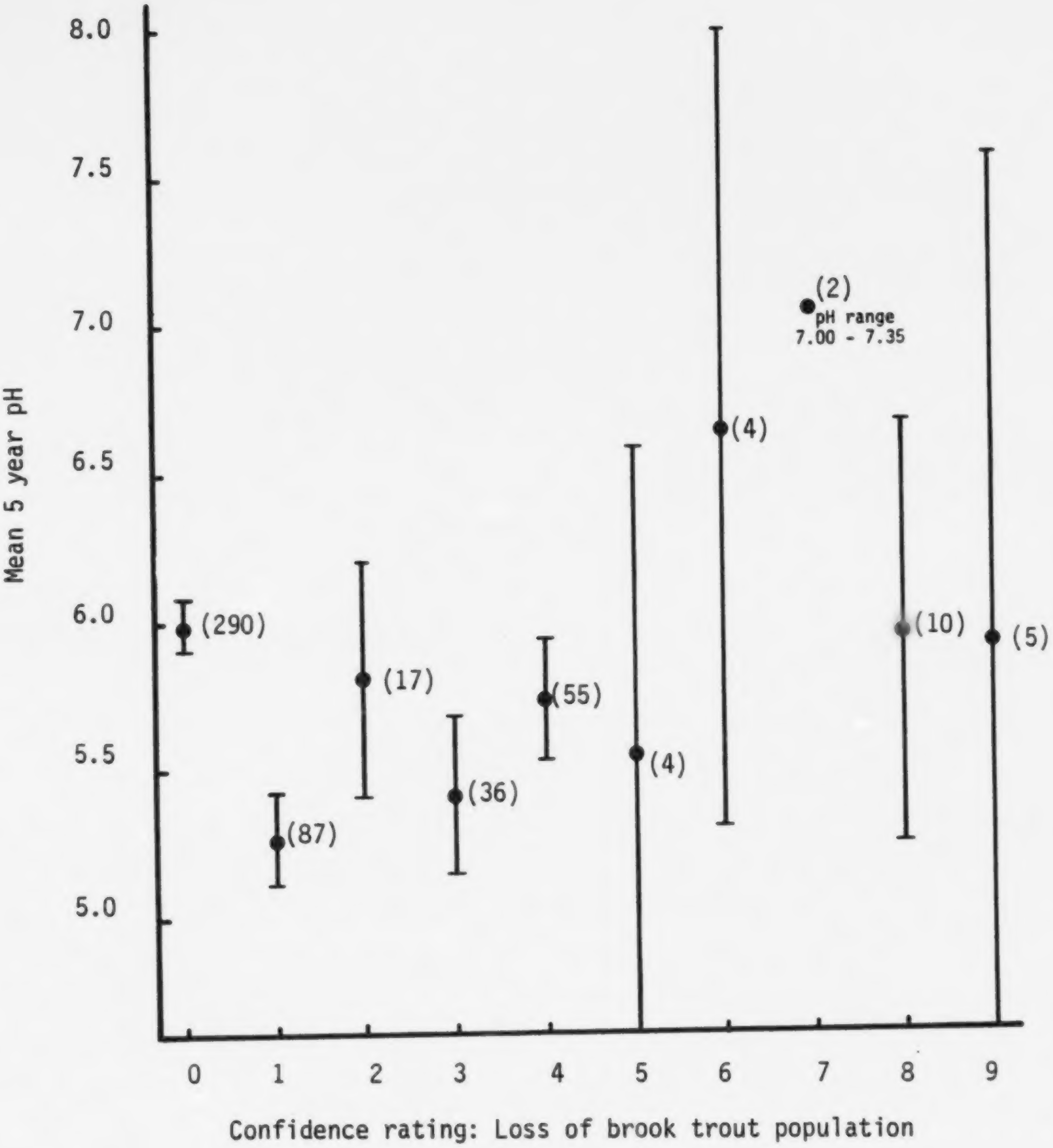

Figure 77. Mean (and 95% confidence intervals) for 5 year pH plotted as a function of the confidence rating for loss of brook trout populations. Number of lakes in parentheses.

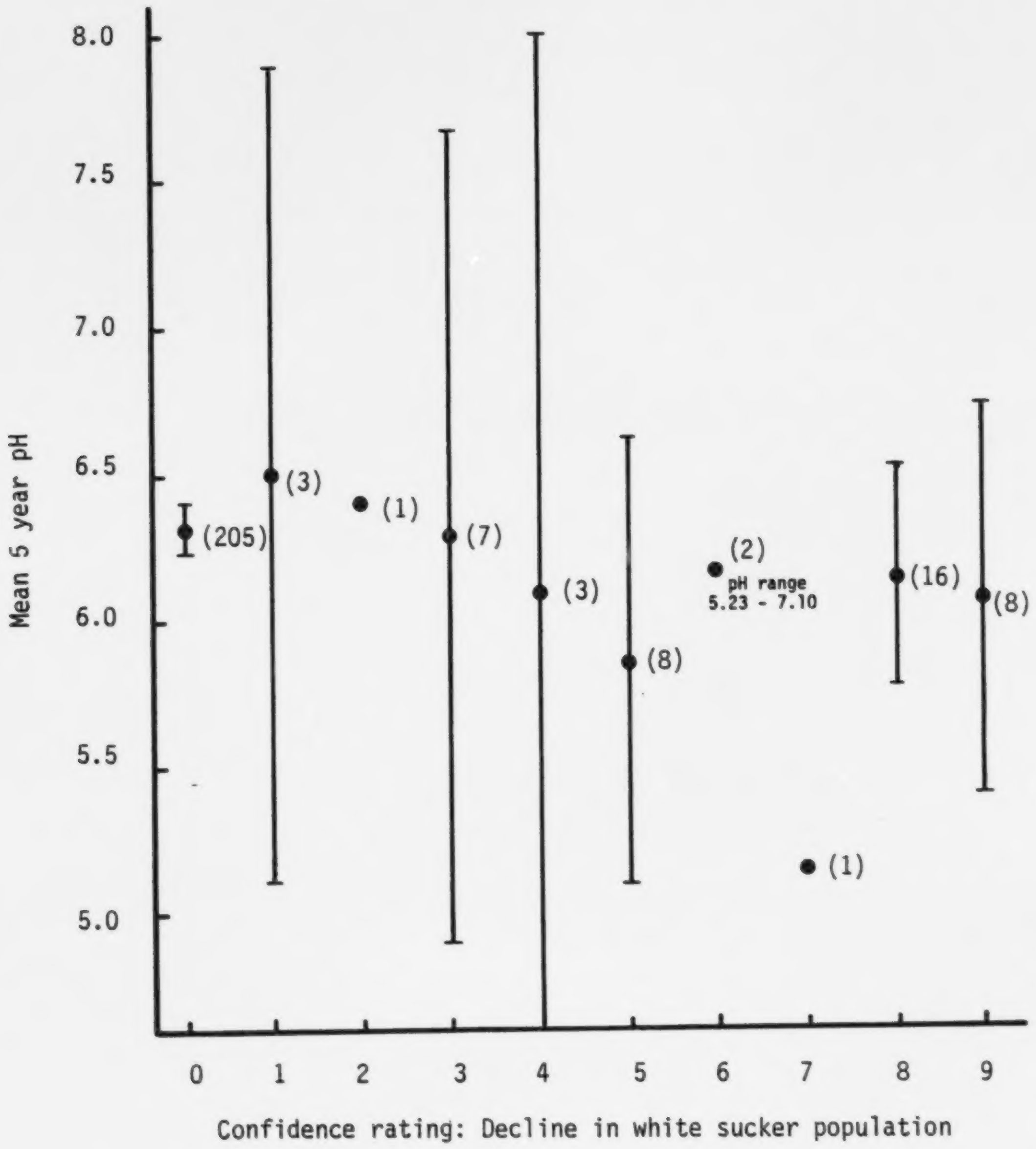

Figure 78. Mean (and 95% confidence intervals) for 5 year pH plotted as a function of the confidence rating for decline of white sucker populations. Number of lakes in parthentheses.

Initially therefore we will test the null hypothesis:

H_0: Ratings of population status, particularly rating the likelihood that changes resulted from acidification, vary independently of lake pH and/or changes in pH over time.

We expect to reject this null hypothesis in favor of the alternate hypothesis:

H_1: Ratings indicating the likelihood that observed decline and/or loss of a fish population resulted from acidification increase with decreasing pH level and/or decreases in pH over time.

For each of the 14 species evaluated, mean pH values (and associated 95% confidence limits) for each rating 0 to 9, indicating the likelihood that an observed decline and/or loss resulted from acidification (i.e., the absence of obvious alternative explanations), are plotted in Figures 79 to 94. pH values used in these analyses are average values for the 5-year period (all pH methodologies) centered around the year of the last fish survey. For all species, pH values for ratings 0 to 4 were not significantly different, as expected, and therefore these ratings have been combined. For the eight species that received at least some ratings > 5, analysis of variance indicated that pH values among ratings (0-4, 5, 6, 7, 8, 9) were significantly different at $p \leq 0.05$. pH values for ratings 6 and higher were consistently lower than $\overline{p}$H values for ratings 0-4, or pH values for lakes with fish populations that have experienced no apparent decline in abundance or condition over time. For populations rated 5, i.e., marginal evidence for effects due to acidification, pH levels were variable, and for many species not significantly different from pH values for ratings 0-4. The null hypothesis is therefore rejected in favor of the alternate hypothesis. The rating system appears to have grouped populations as expected.

The above analyses and Figures 79 to 94 consider all populations with any indications of decline or loss over time, i.e. populations receiving confidence ratings > 0 for population decline and/or loss. It is possible that the relationship between the 'likelihood' rating and lake pH changes with increasing confidence that a decline or loss of the fish population has actually occurred. This does not, however, appear to be the case (e.g., Figures 95 and 96).

Brook trout populations deserve special attention (Figure 97). Surveys of brook trout waters potentially impacted by acidic deposition have intensified in recent years. As a result, a substantial number of lakes considered 'typical brook trout habitat' have recent survey data but no information on fish populations prior to the 1970's. Three situations were discussed in Section 10, considering the status of fish communities: (1) lakes stocked with brook trout but no fish caught, (2) lakes with only recent surveys and no fish caught, and (3) lakes with only recent surveys and only brook trout and/or brown bullhead. These lakes were considered separately in analysis of fish community status, but were included in ratings of brook trout population status. For example, lakes with no fish caught but considered 'typical brook trout habitat' and with no reasons for

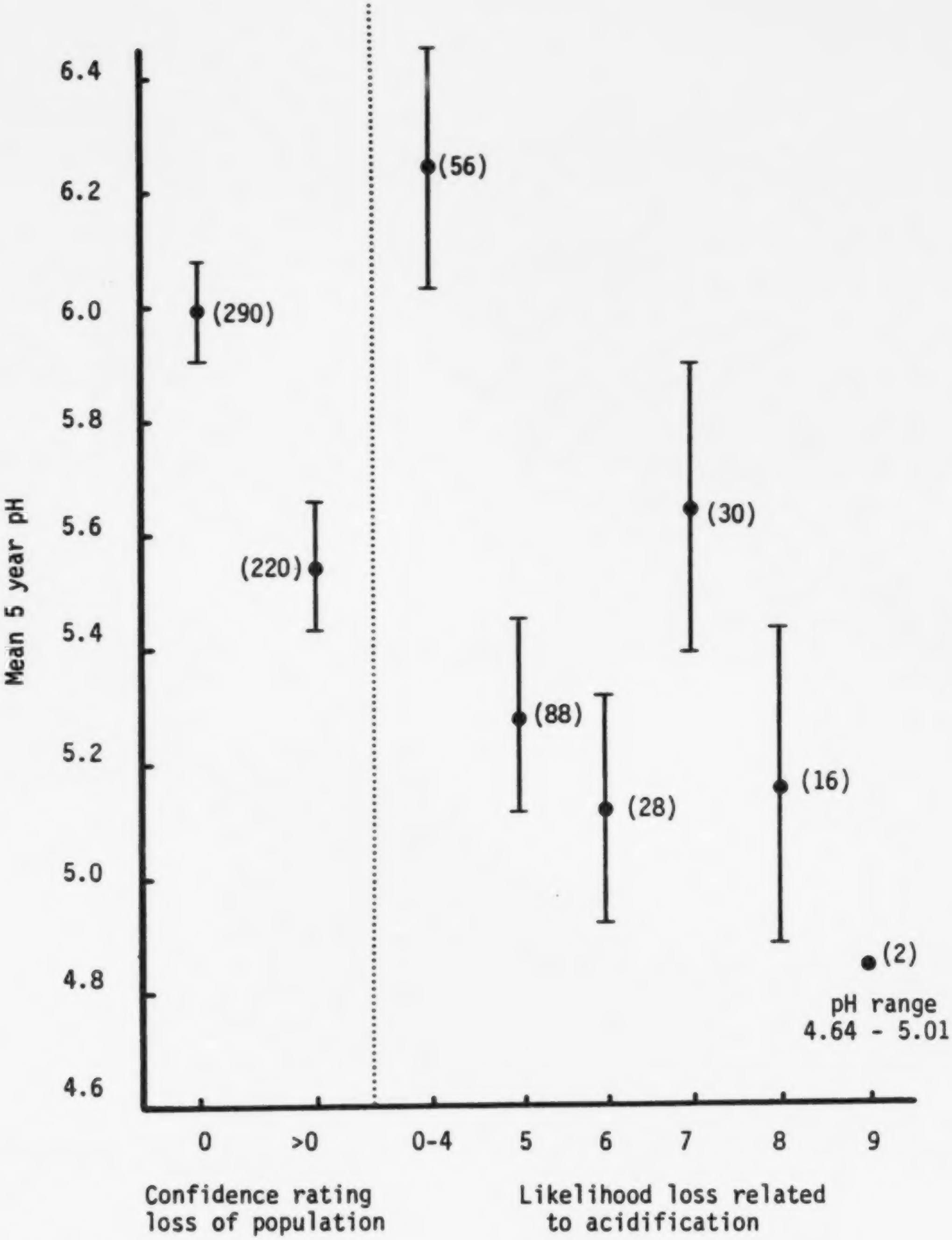

Figure 79. Mean (and 95% confidence intervals) for mean 5-year pH by ratings of brook trout population status. Number of lakes in parentheses.

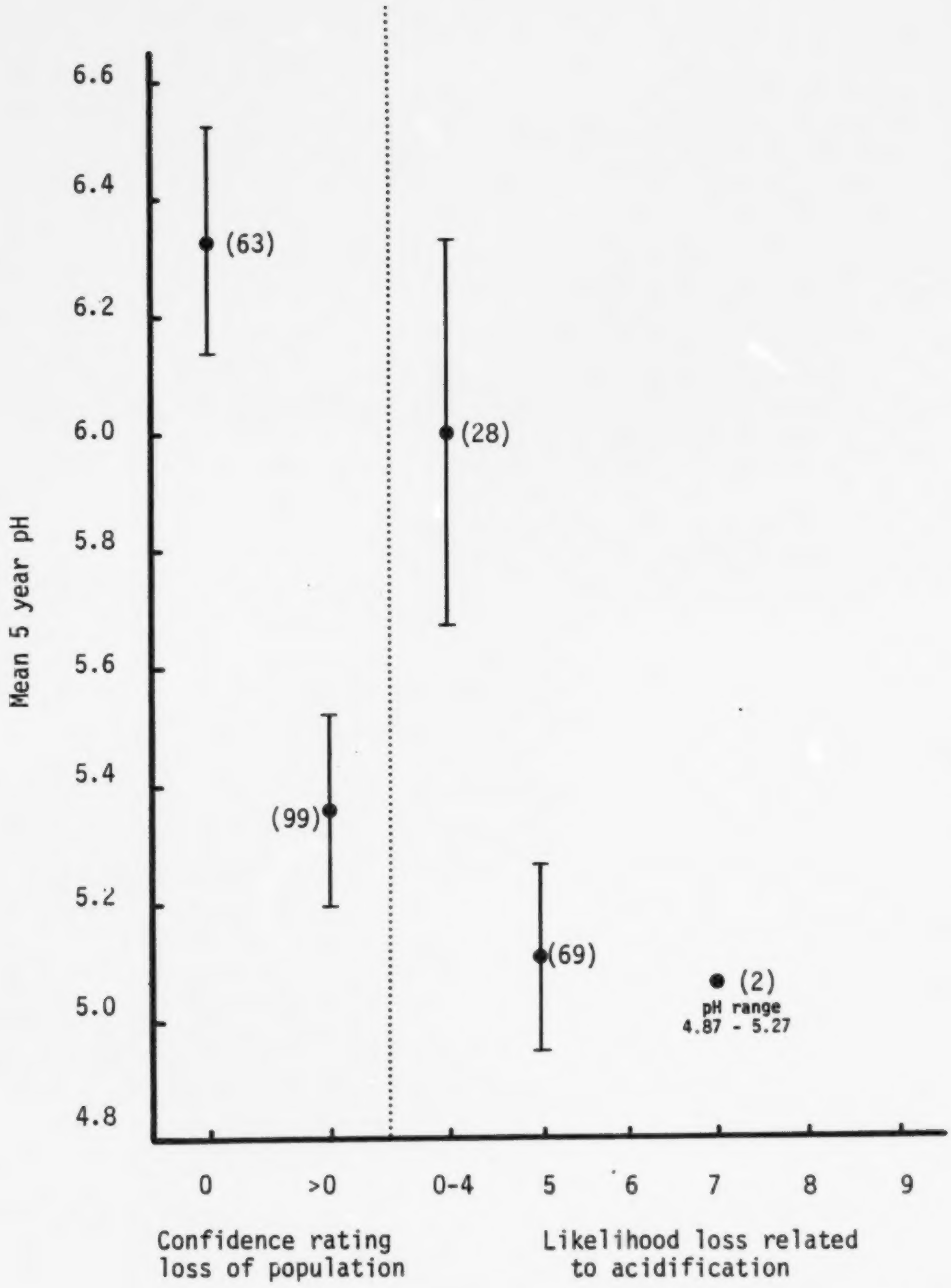

Figure 80. Mean (and 95% confidence intervals) for mean 5-year pH by ratings of brook trout population status, naturally reproducing populations only. Number of lakes in parentheses.

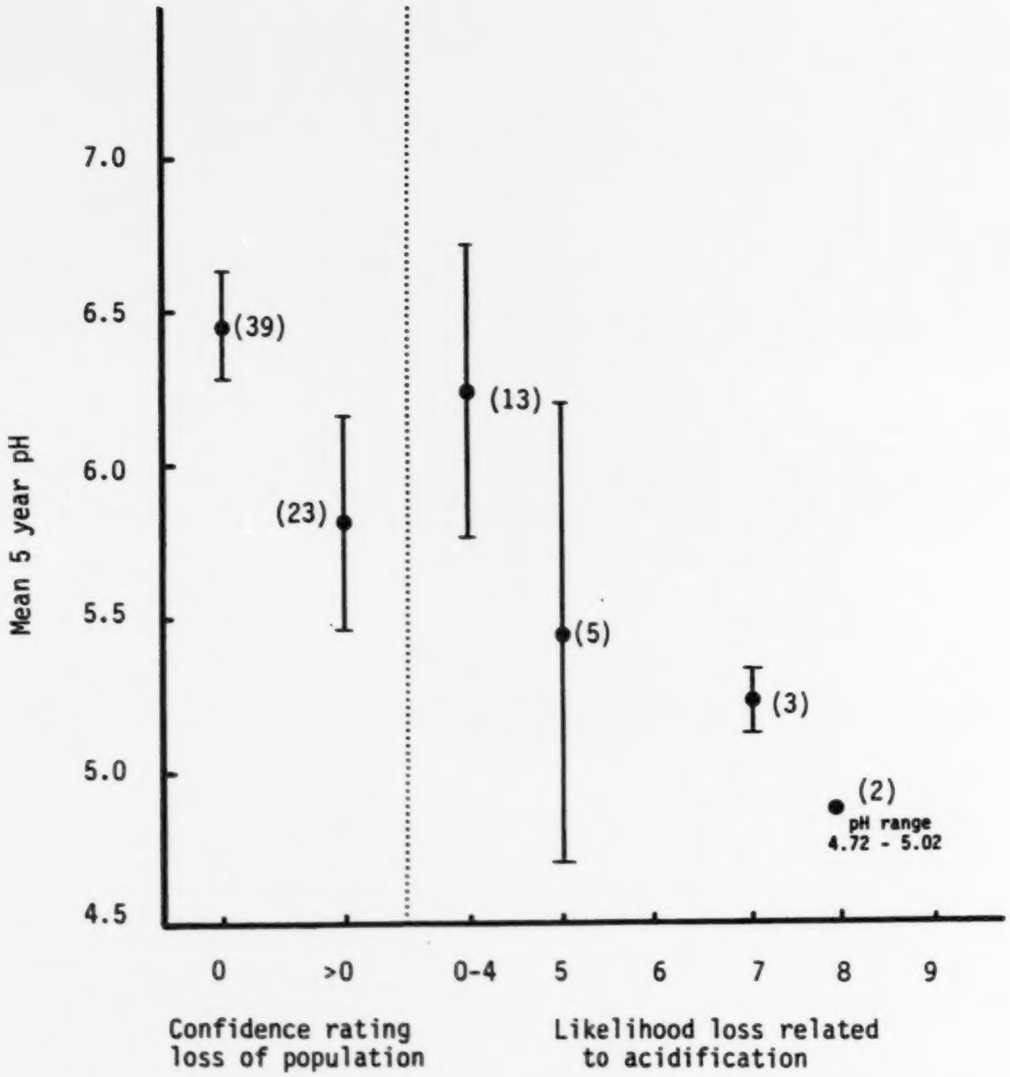

Figure 81. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of lake trout population status. Number of lakes in parentheses.

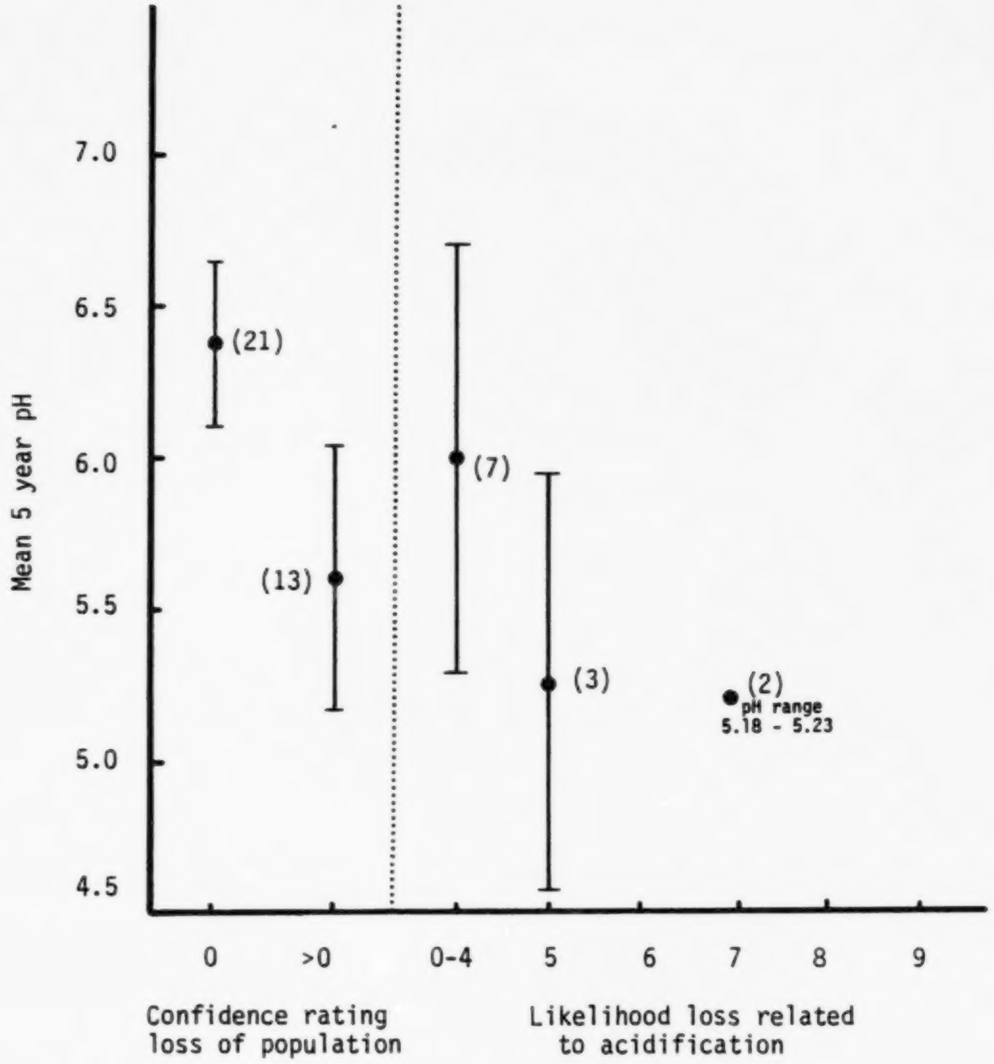

Figure 82. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of lake trout population status, naturally reproducing populations only. Number of lakes in parentheses.

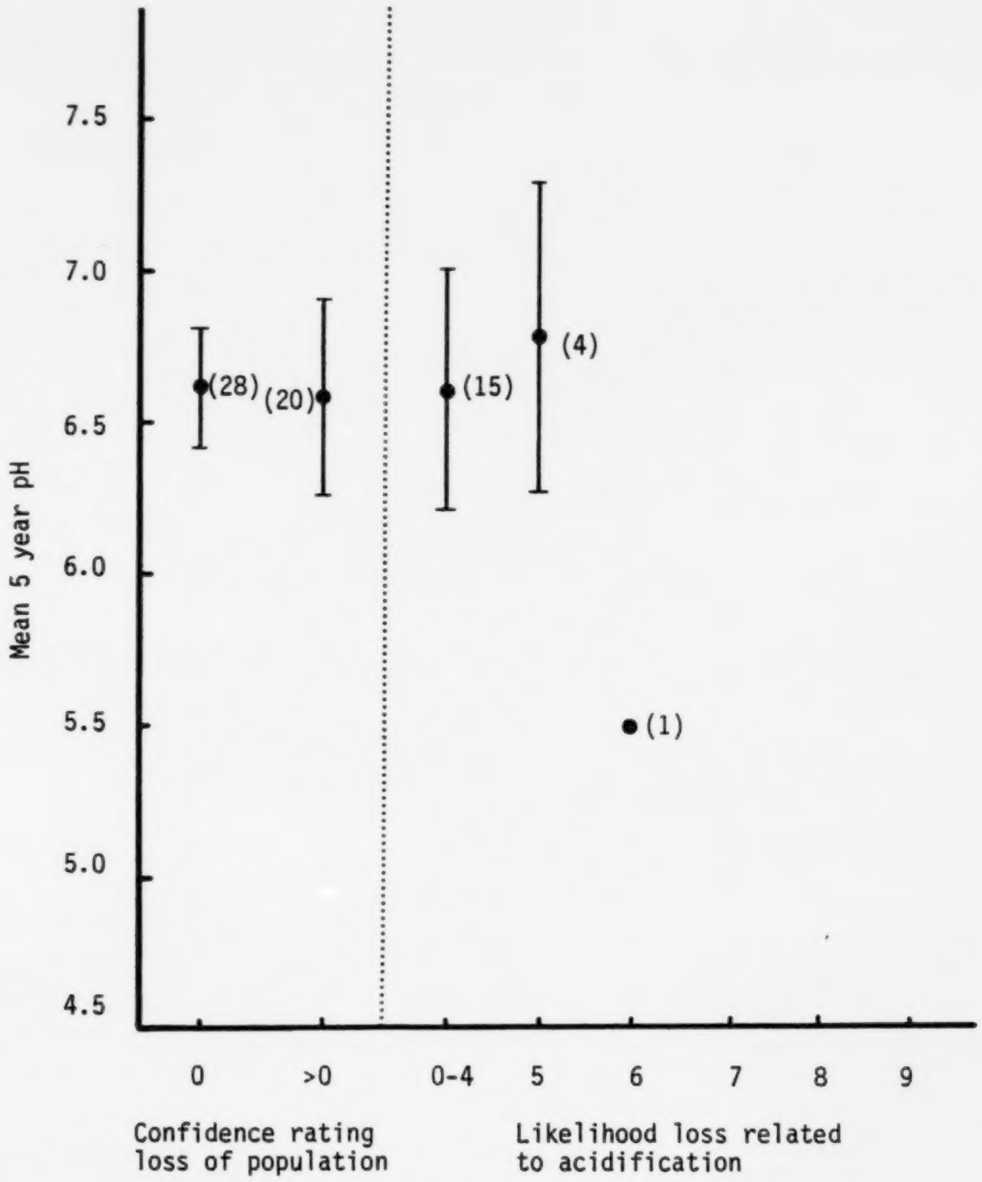

Figure 83. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of rainbow trout population status. Number of lakes in parentheses.

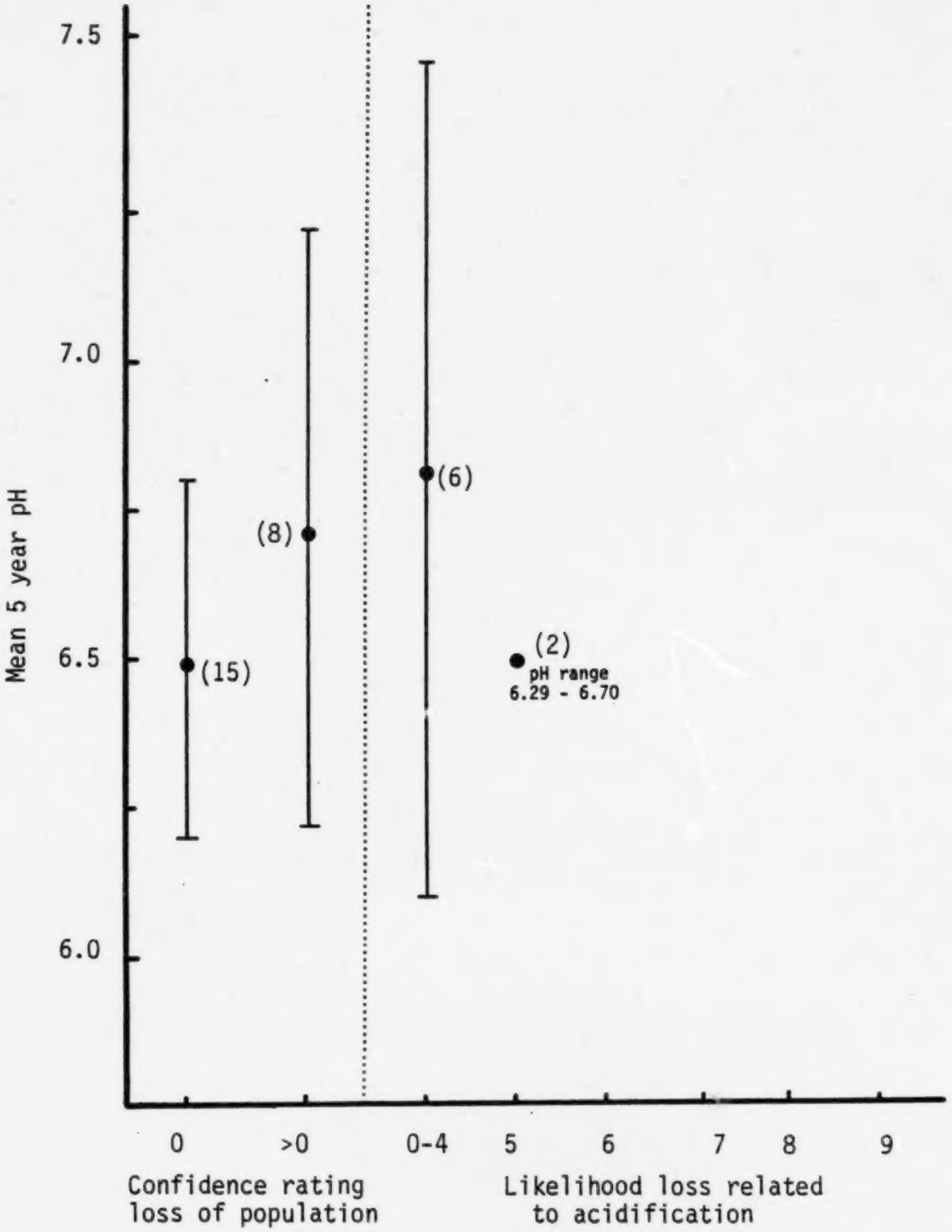

Figure 84. Mean (and 95% confidence intervals) for 5 mean year pH ratings of lake whitefish population status. Number of lakes in parentheses.

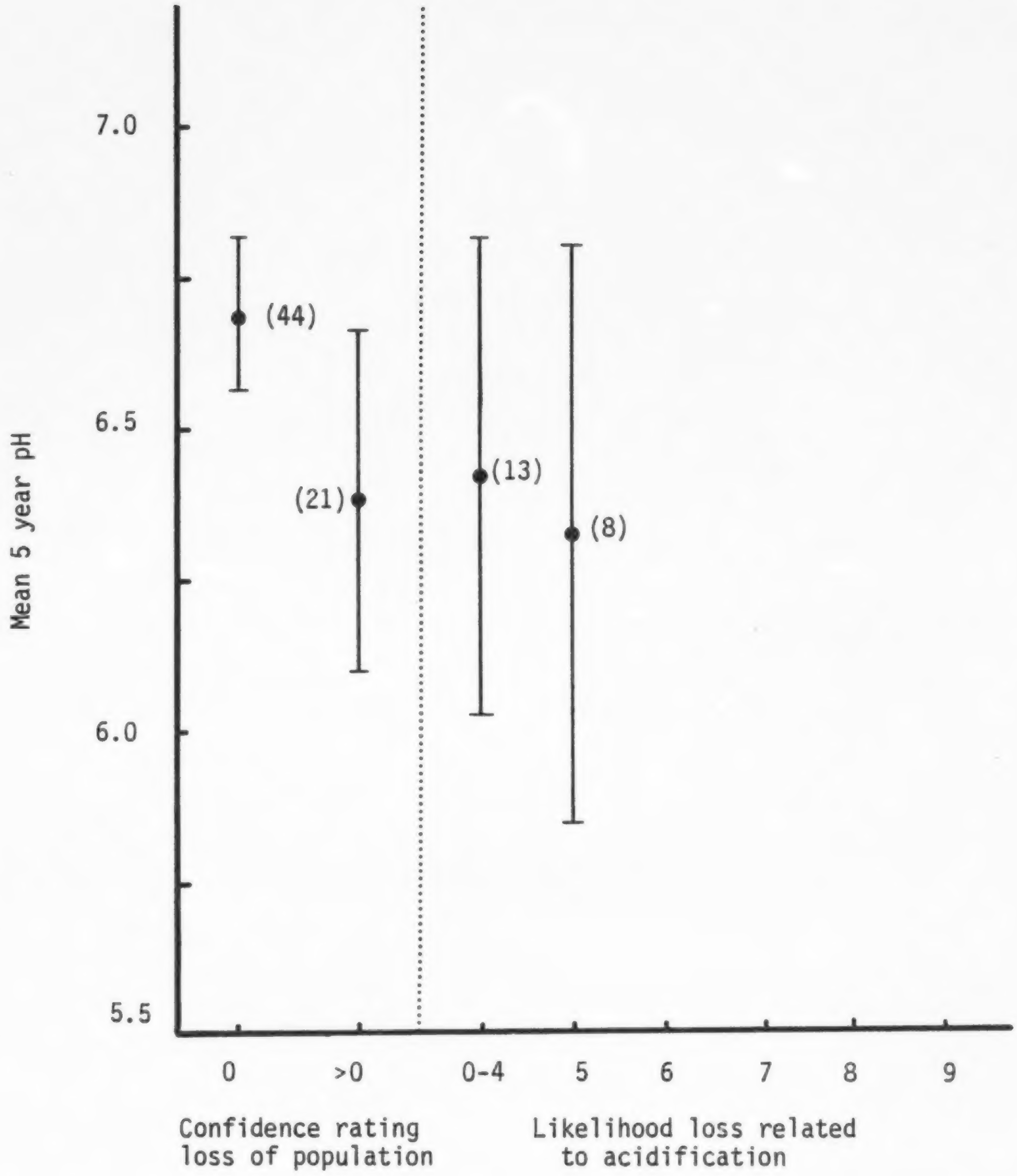

Figure 85. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of smallmouth bass population status. Number of lakes in parentheses.

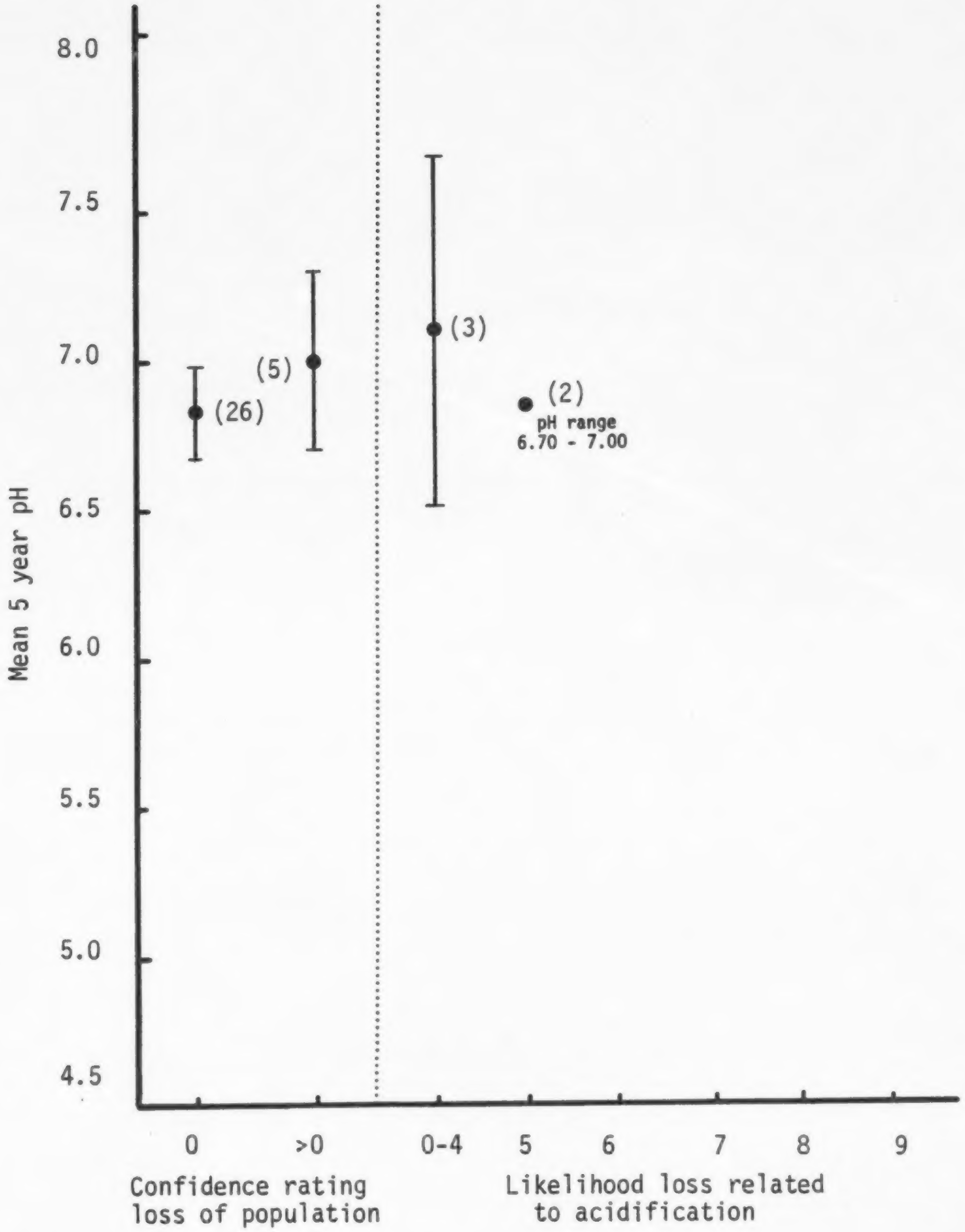

Figure 86. Mean (and 95% confidence intervals) for mean 5 year pH by rating of largemouth bass population status. Number of lakes in parentheses.

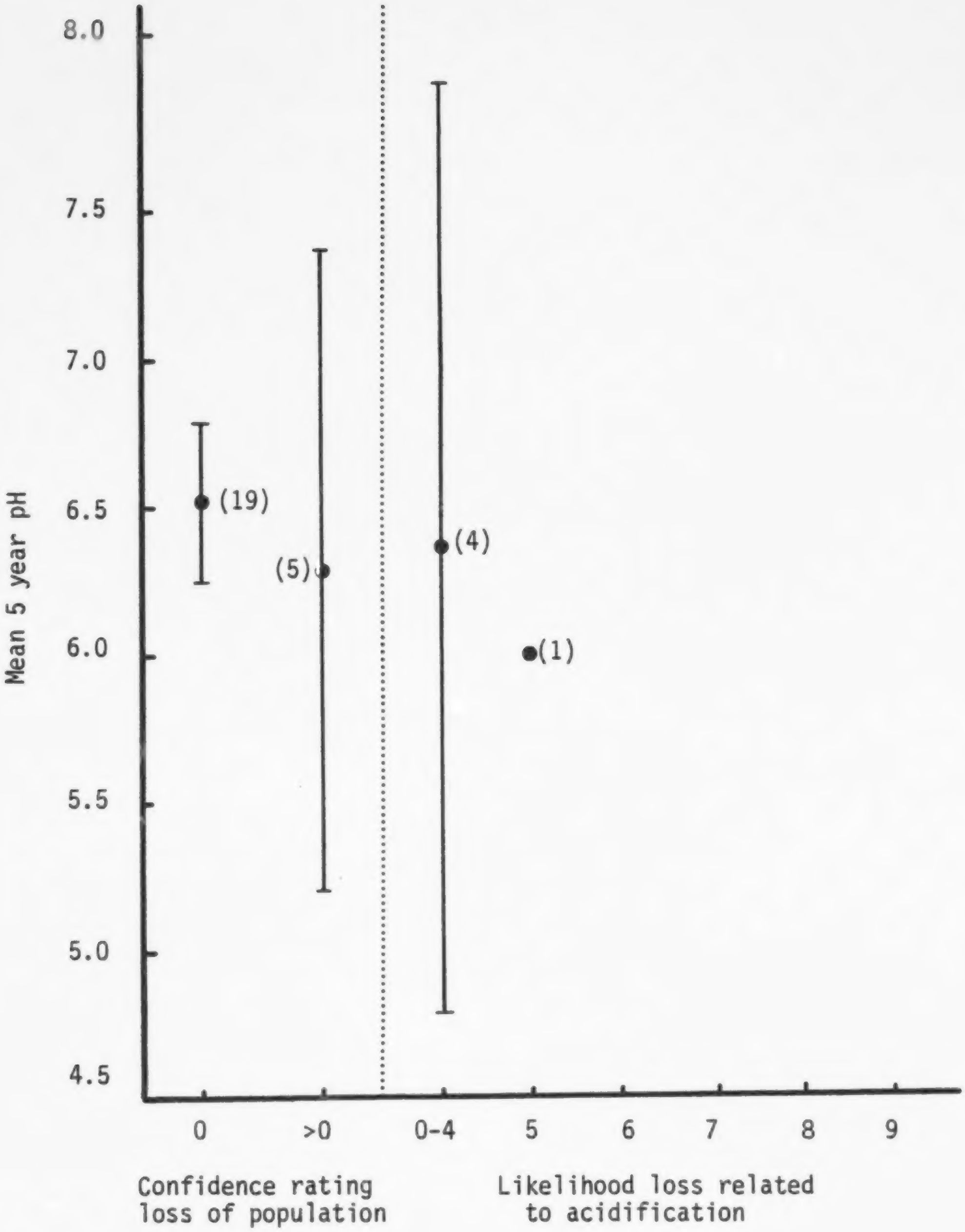

Figure 87. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of chain pickerel population status. Number of lakes in parentheses.

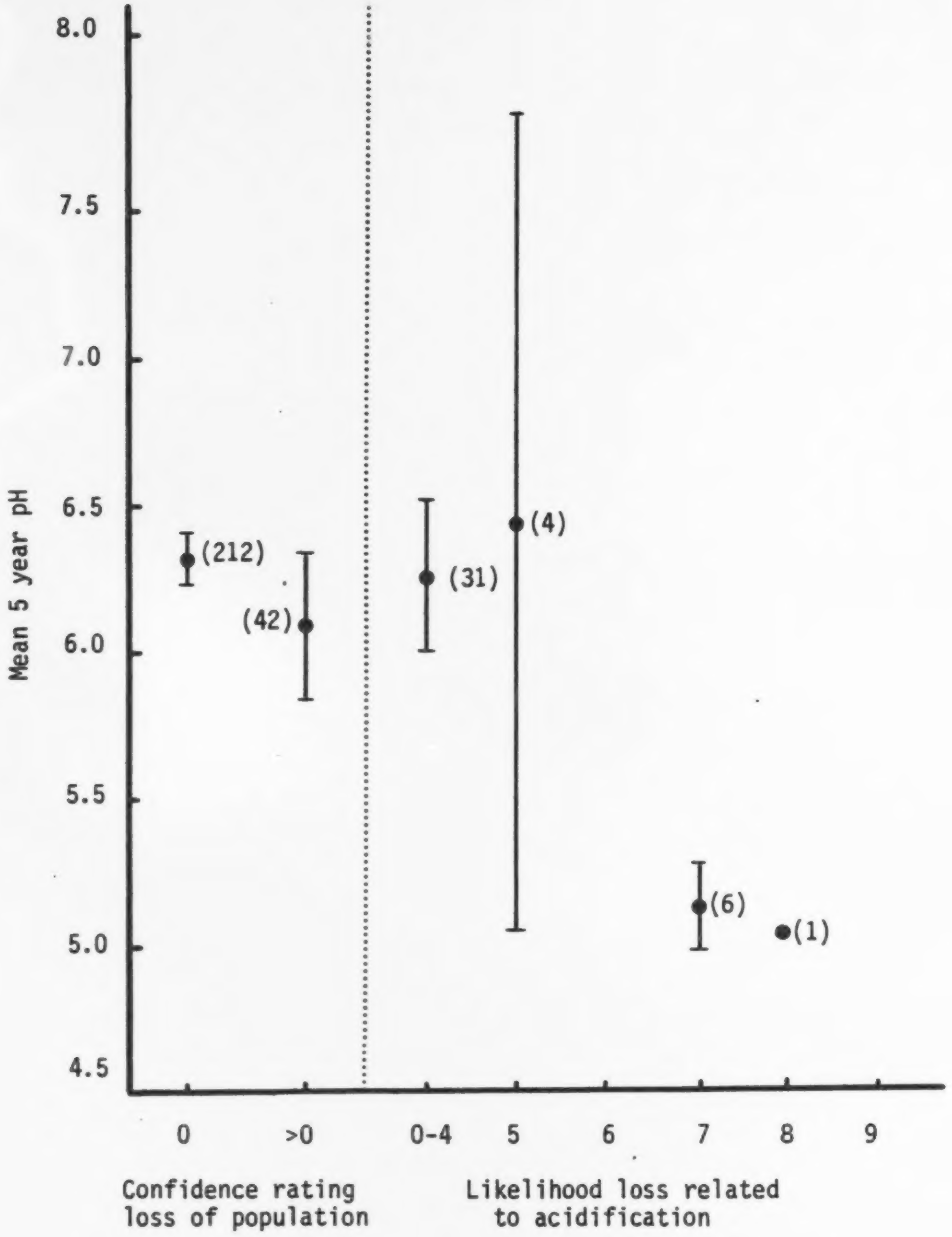

Figure 88. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of white sucker population status. Number of lakes in parentheses.

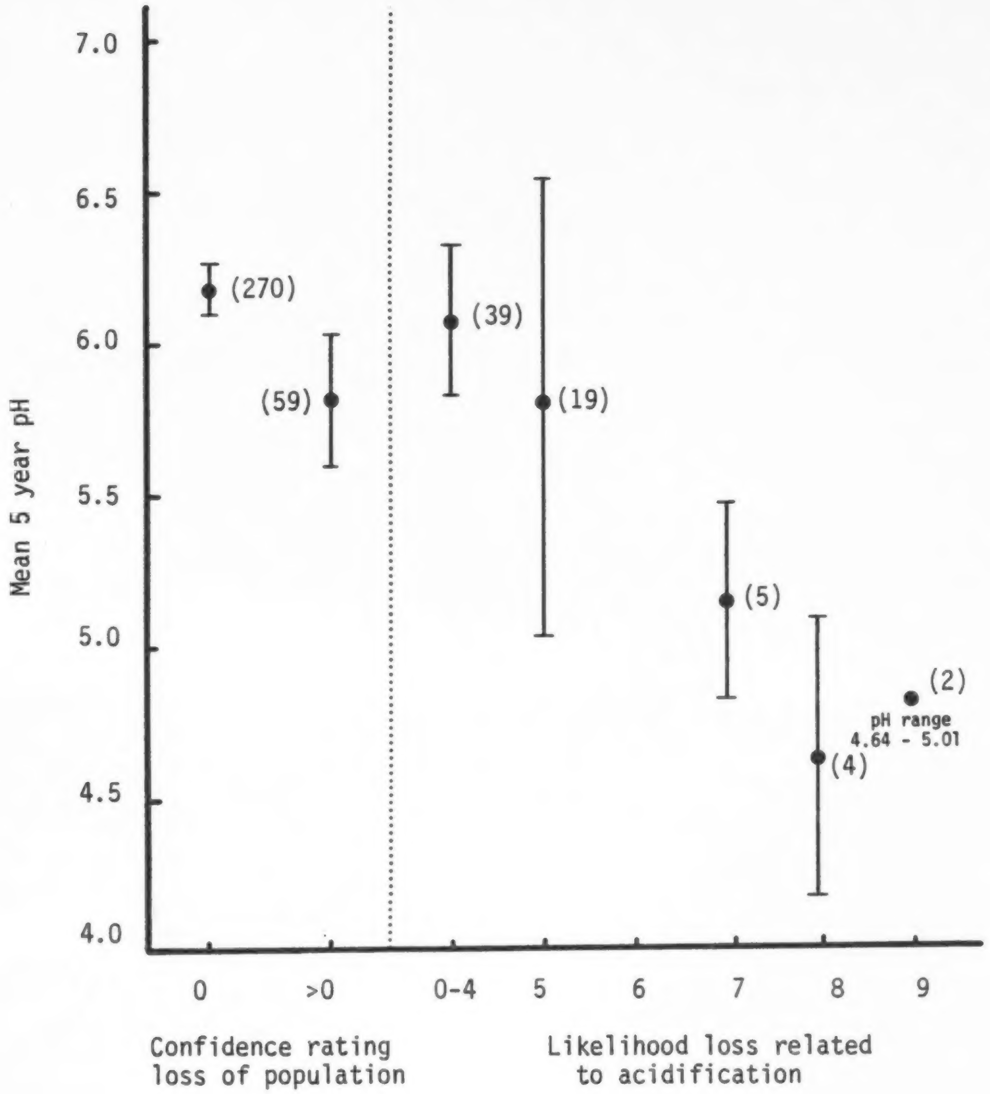

Figure 89. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of brown bullhead population status. Number of lakes in parentheses.

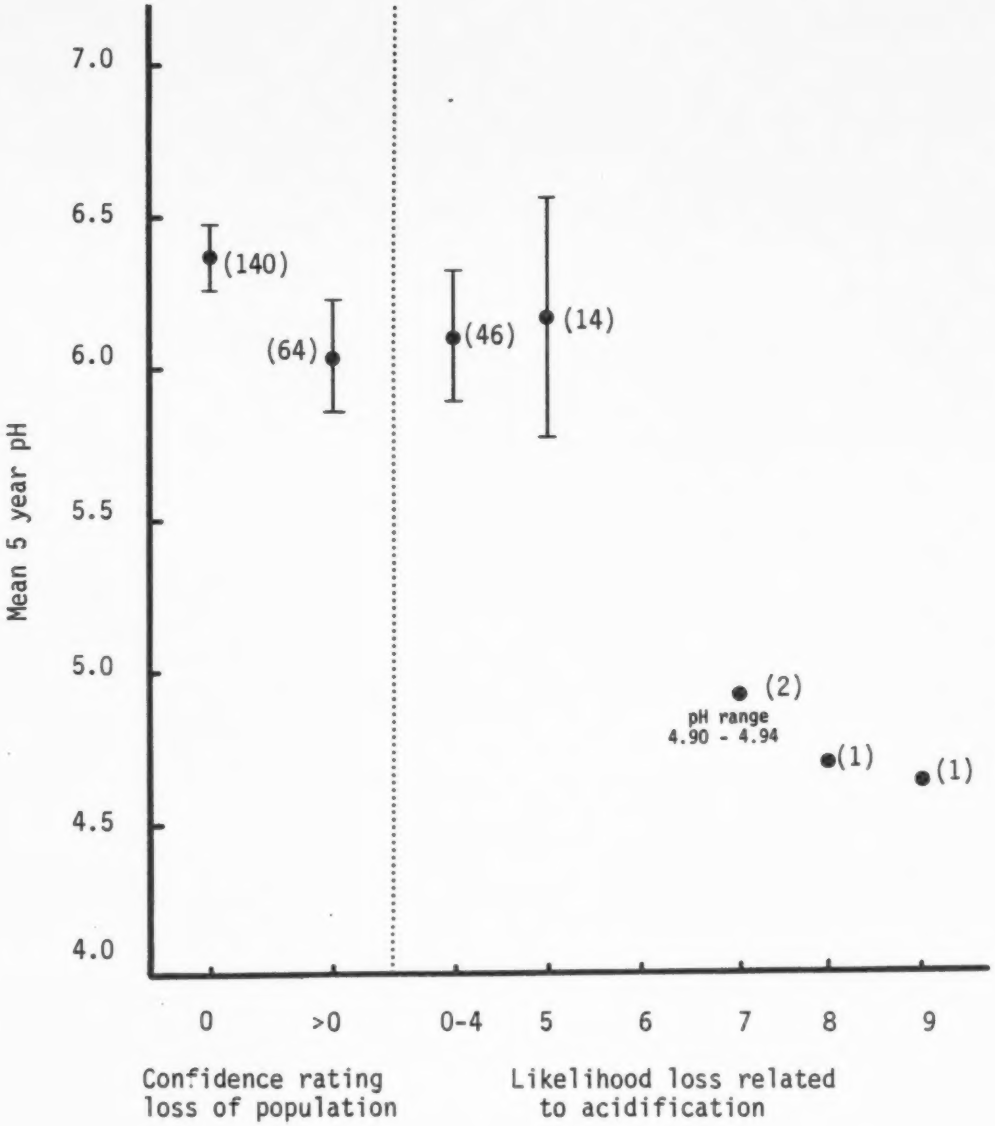

Figure 90. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of pumpkinseed sunfish population status. Number of lakes in parentheses.

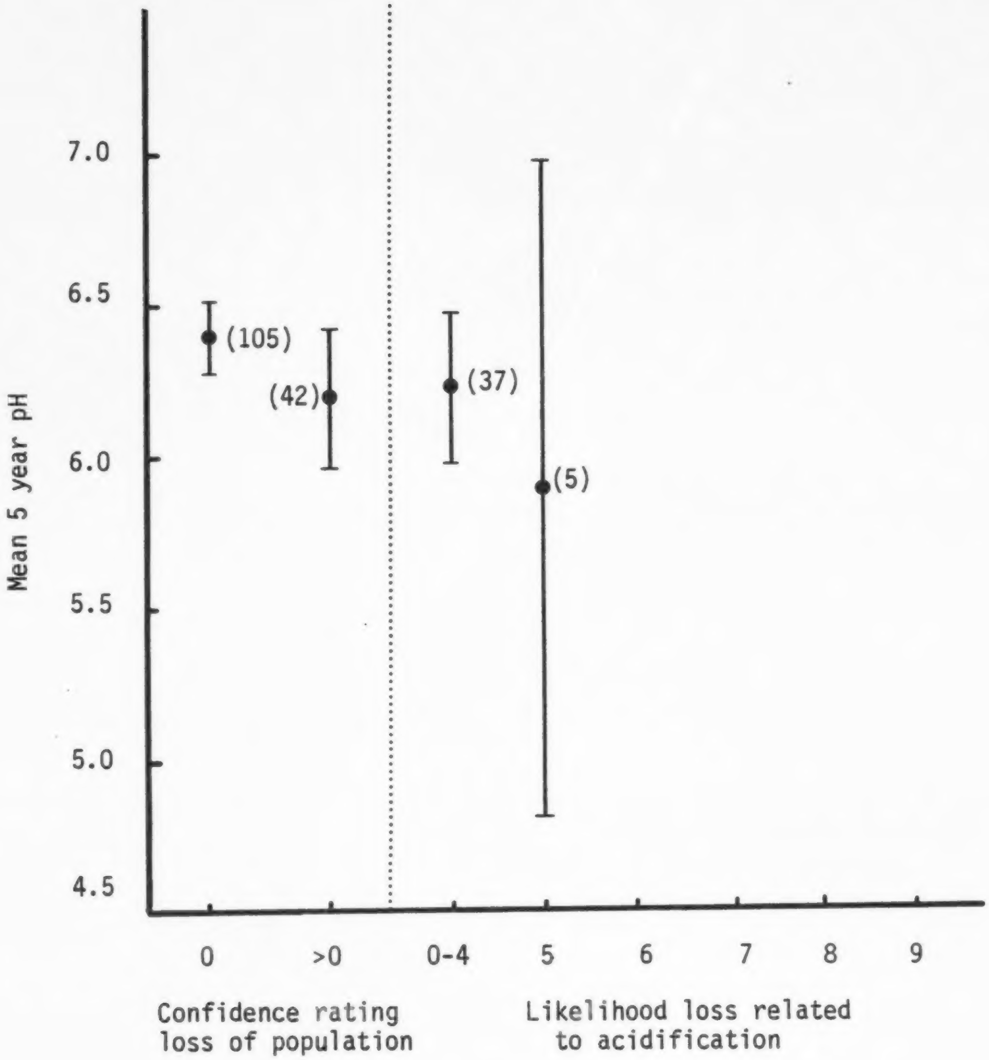

Figure 91. Mean (and 95% confidence intervals) for mean 5 year pH by ratings of yellow perch population status. Number of lakes in parentheses.

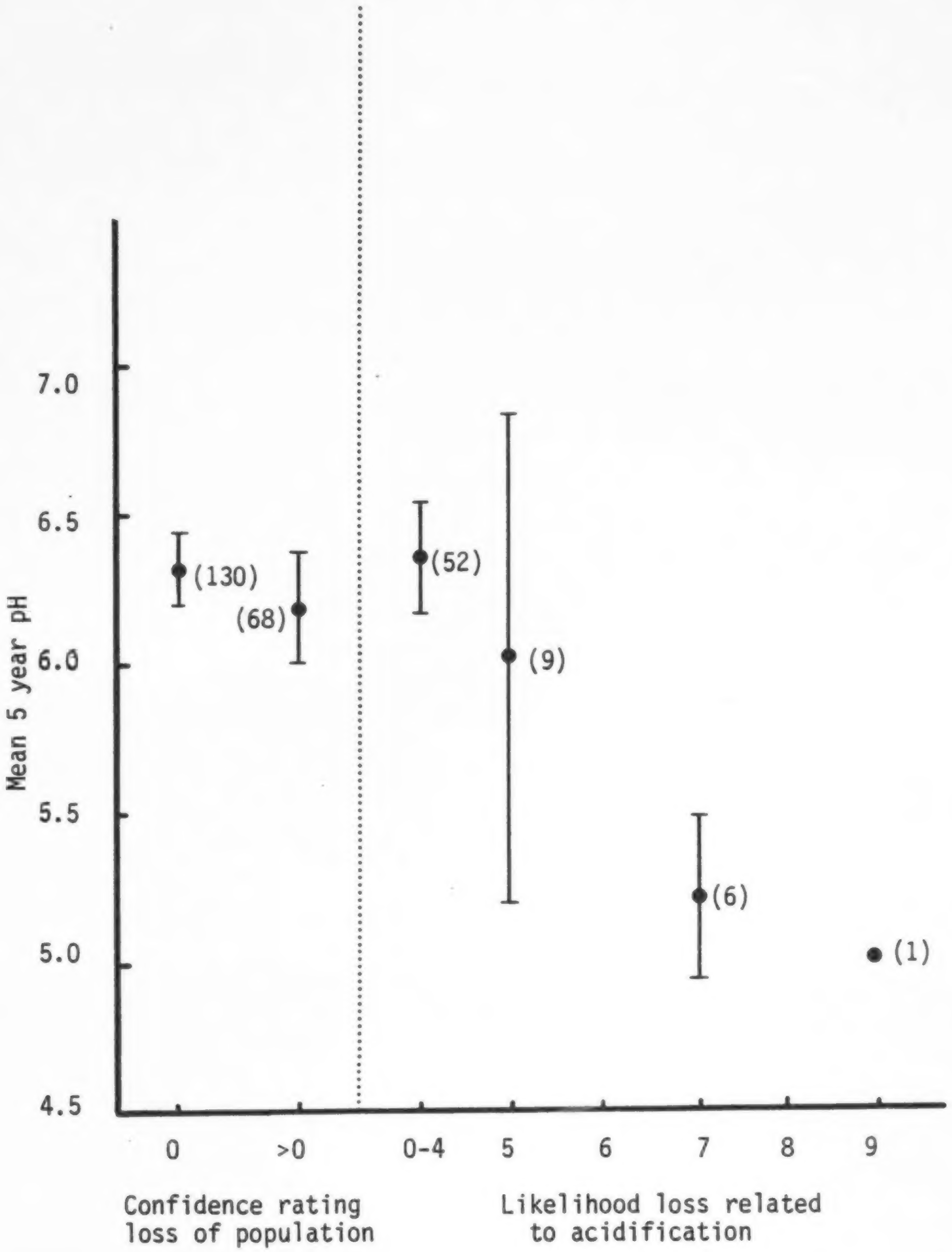

Figure 92. Mean (and 95% confidence intervals) for mean 5 year pH by rating of golden shiner population status. Number of lakes in parentheses.

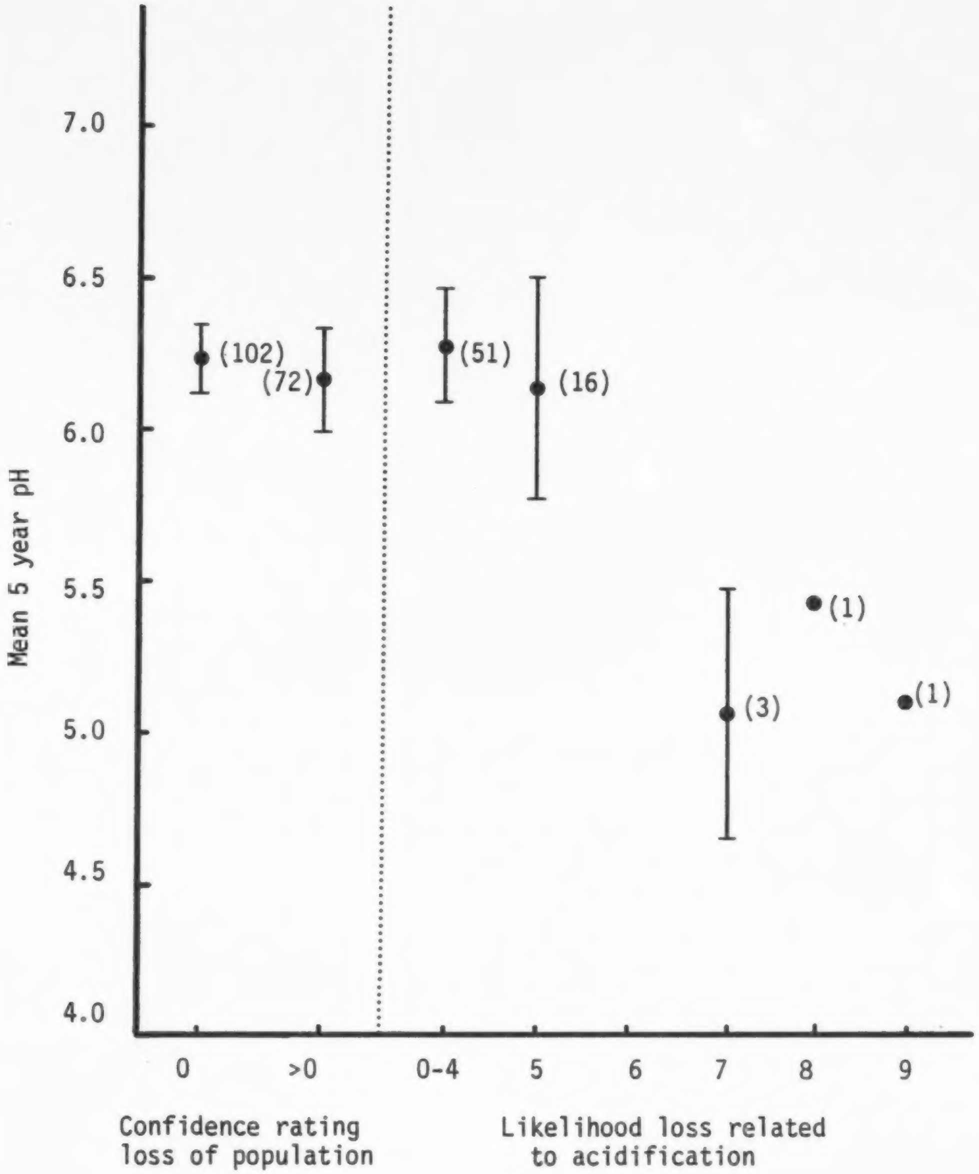

Figure 93. Mean (95% confidence intervals) for mean 5 year pH by ratings of creek chub population status. Number of lakes in parentheses.

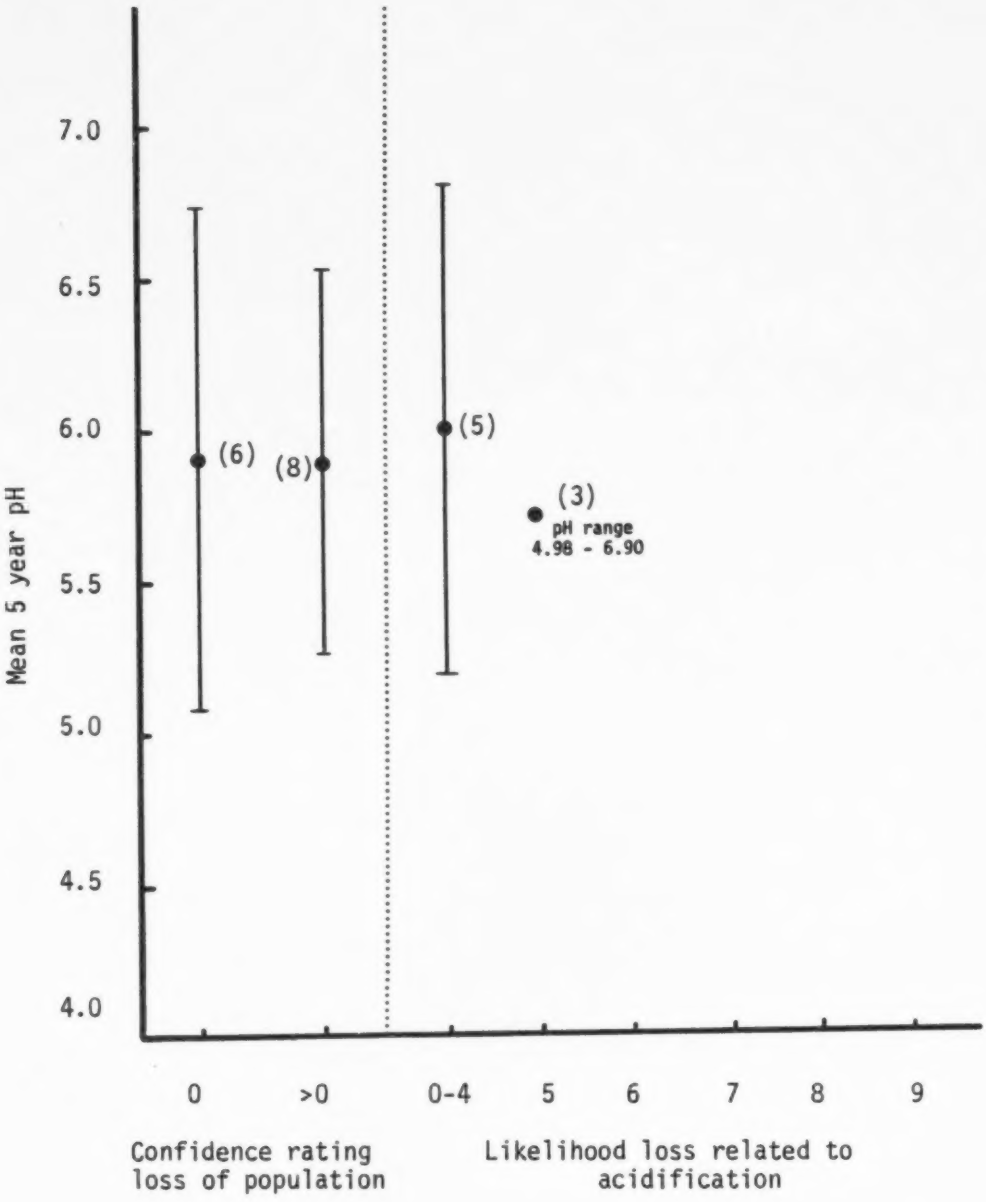

Figure 94. Mean (and 95% confidence intervals) for mean 5 year pH by rating of lake chub population status. Number of lakes in parentheses.

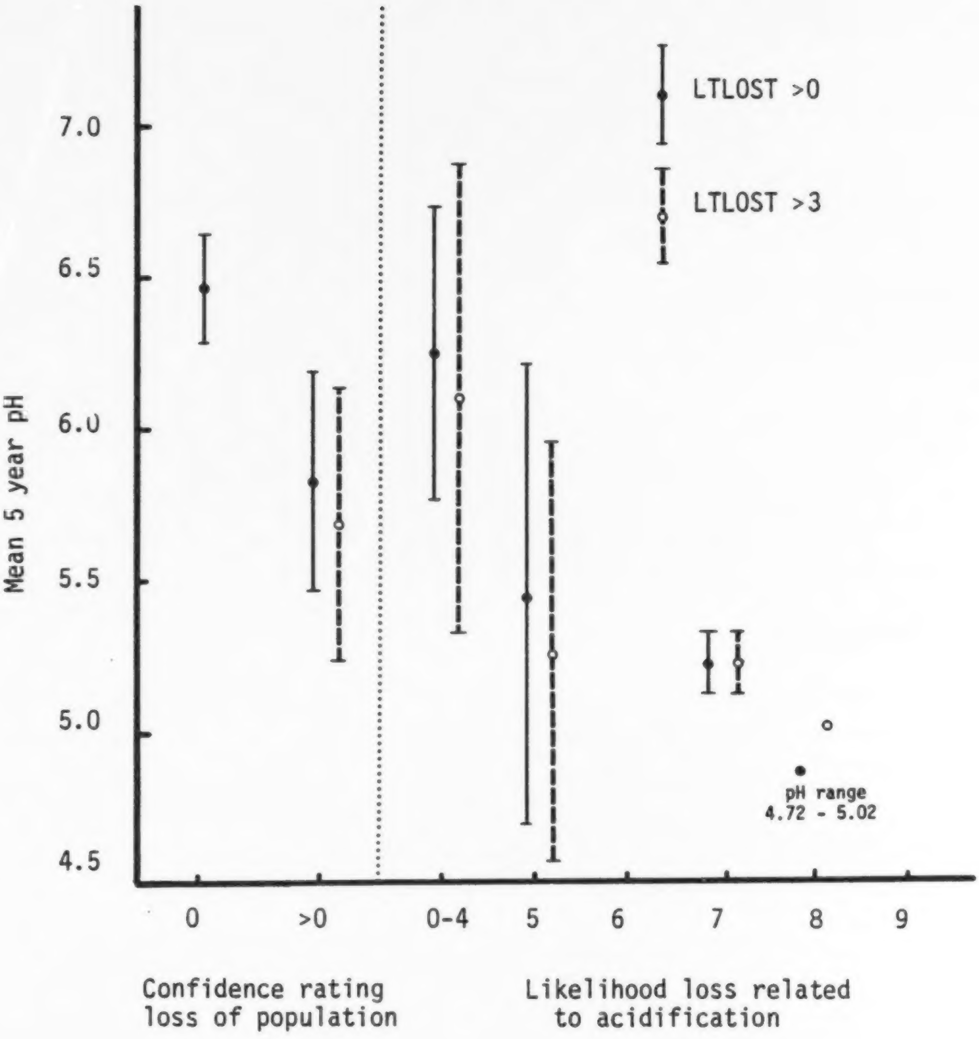

Figure 95. Mean (and 95% confidence intervals) for mean 5-year pH by ratings of lake trout population status, at two levels of confidence regarding loss of population.

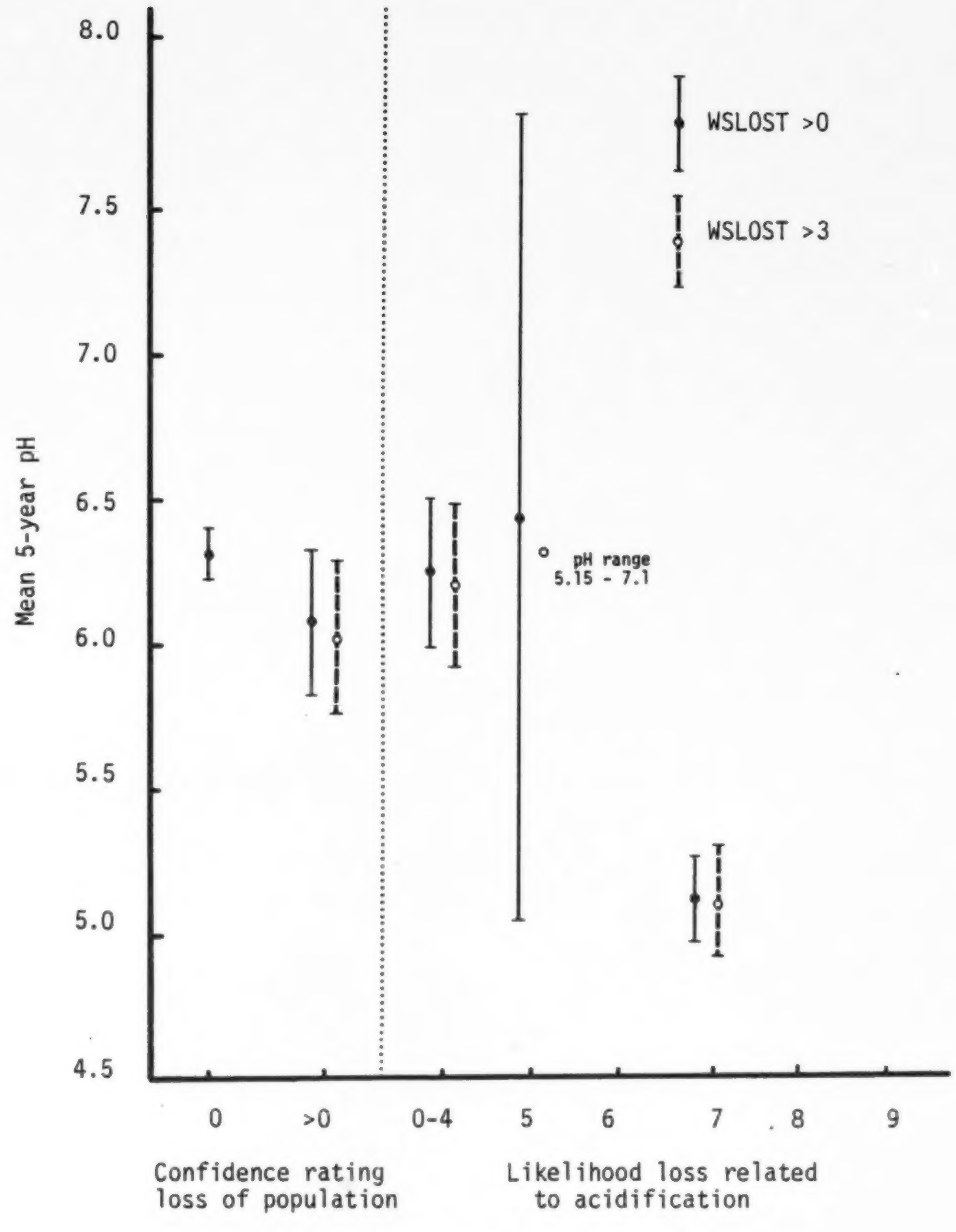

Figure 96. Mean (and 95% confidence intervals) for mean 5-year pH by ratings of white sucker population status, at two levels of confidence regarding loss of population.

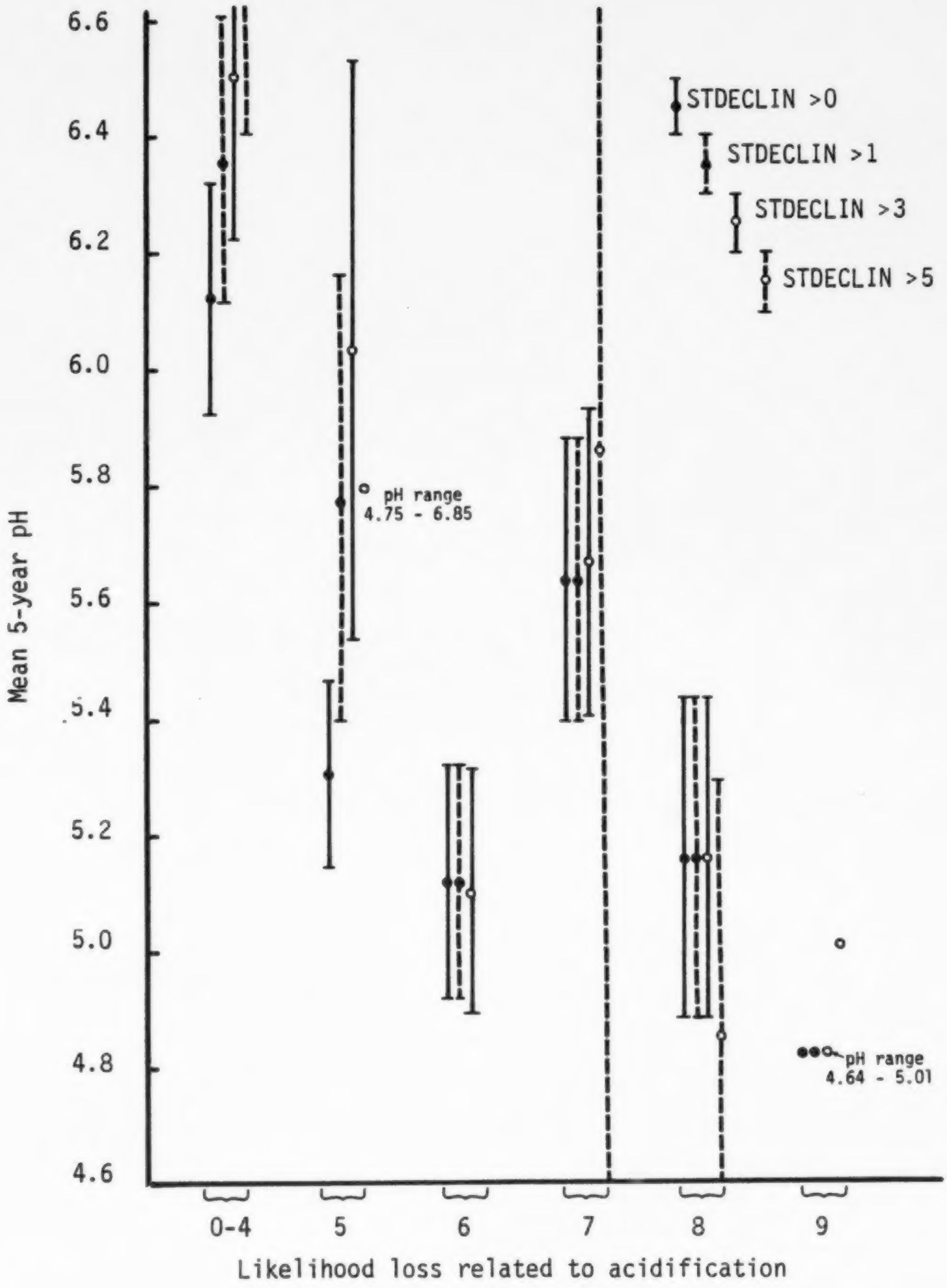

Figure 97. Mean (and 95% confidence interval) for mean 5-year pH by ratings of brook trout population status at four levels of confidence regarding loss of population.

the lack of trout noted in the written comments (other than perhaps acidification), received very low confidence ratings (i.e., rating = 1) regarding evidence for a decline or loss of the population over time, and a marginal rating (i.e., 5) for likelihood that the decline/loss resulted from acidification. Thus, as we restrict the analysis to populations with higher confidence ratings, these lakes are excluded. As a group, lakes with no fish or brook trout stocking failure had quite low pH levels (mean pH 5.16 and 5.11, respectively). Exclusion of these lakes therefore increases the overall mean pH (Figure 97).

As for ratings of fish community status, ratings of population status are more clearly associated with lake pH than with the rate of change in pH over time (Figures 98 to 100). Rate of pH change and current lake pH are highly correlated ($p \leq 0.001$). Differences in rate of pH change among ratings of fish population status are not significant ($p > 0.05$) after adjusting for differences associated with current pH.

Ratings ≥ 6 for the likelihood that fish population decline or loss resulted from acidification were significantly correlated with low pH levels. All species except chain pickerel and lake chub had some populations that received a rating ≥ 6 (Figures 79-94, and Appendix Tables A6-A21). Thus the evidence suggests that some fish populations have been lost from Adirondack lakes as a result of acidification.

12. HOW MANY FISH POPULATIONS HAVE BEEN LOST FROM ADIRONDACK LAKES APPARENTLY AS A RESULT OF ACIDIFICATION?

Problems associated with counting up the number of fish communities receiving ratings indicative of adverse effects due to acidification were reviewed in detail in Section 10. Similar considerations are appropriate here for counts of numbers of fish populations adversely affected. In essence, we are aware that we will never know the answer to how many fish populations have been lost. We have no sample of populations of known status, from which we could estimate the error associated with our ratings of population status. Numbers of populations with 'adequate evidence' indicative of adverse effects of acidification also vary with each individual's definition of 'adequate evidence'. Finally, our sample of lakes for which we have estimated fish population status was not selected randomly. Lakes with both historic and recent fish survey data tend to be larger (Figure 74) and have higher pH (Figure 75) than Adirondack lakes in general.

We will not, therefore, attempt to answer the question: how many fish populations have been lost as a result of acidification? Instead we simply report the numbers of populations at each rating level indicative of population decline or loss and the likelihood that the decline or loss resulted from acidification (Appendix Tables A6-A21). These data are summarized in Table 8.

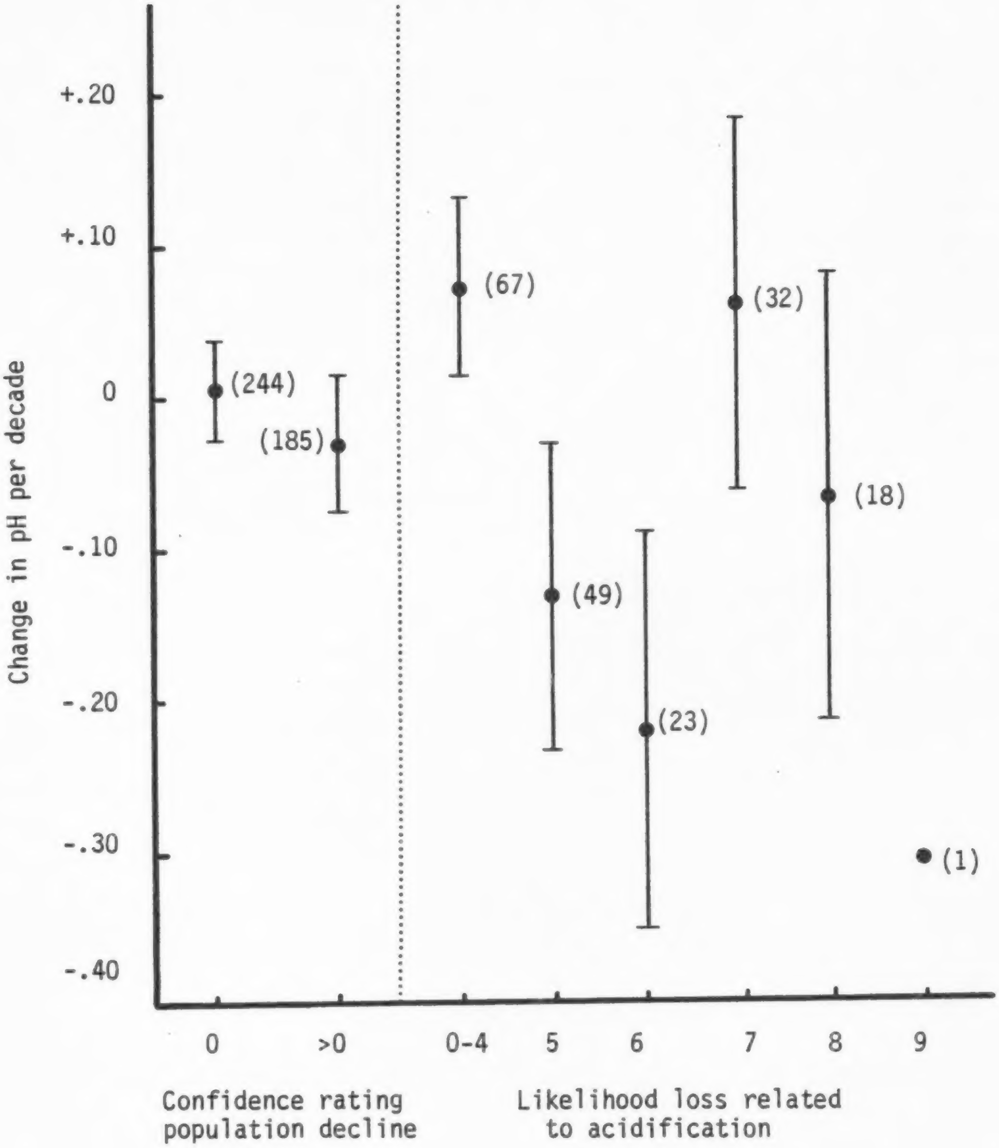

Figure 98. Mean (and 95% confidence intervals) for rate of change in pH over time, by ratings of brook trout population status. Number of lakes in parentheses.

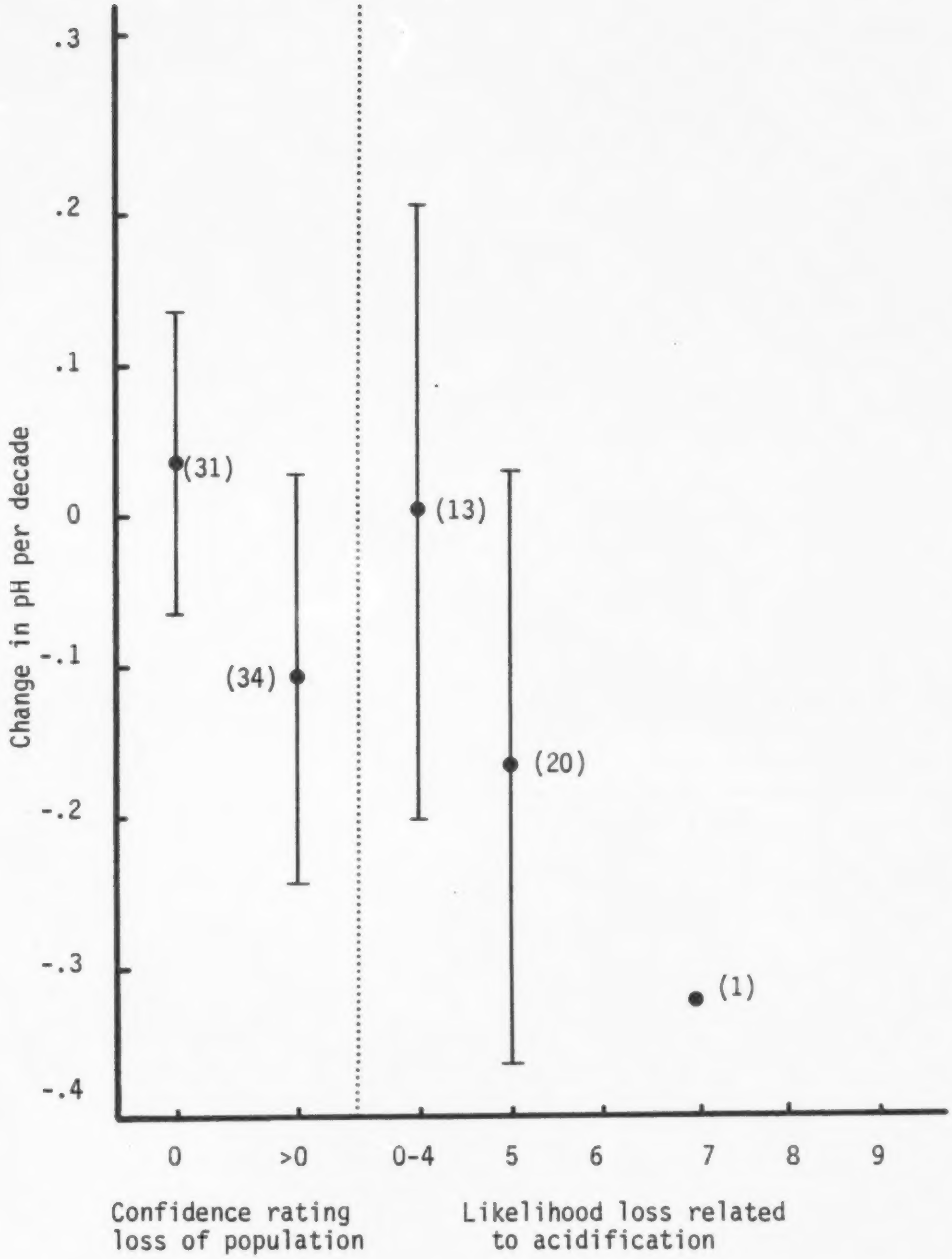

Figure 99. Mean (and 95% confidence intervals) for rate of change in pH over time, by ratings of brook trout population status, naturally reproducing populations only. Number of lakes in parentheses.

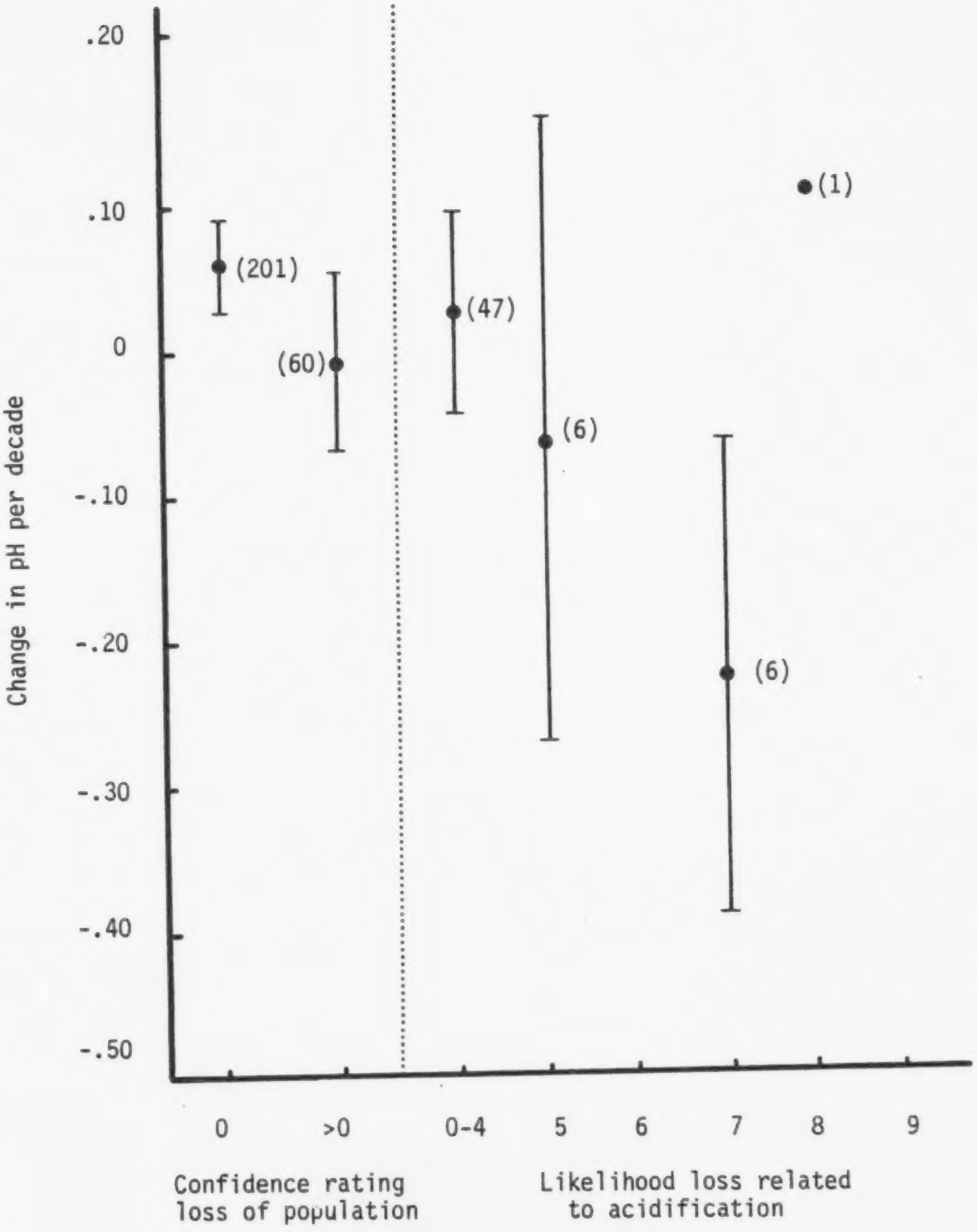

Figure 100. Mean (and 95% confidence intervals) for rate of change in pH over time by ratings of white sucker population status. Number of lakes in parentheses.

Table 8. Numbers of populations classified by ratings of population status and likely adverse effects of acidification (i.e., absence of obvious alternative explanations for population loss).

Species	No evidence for loss of population	Loss Apparently unrelated to acidification	Loss Apparently as a result of acidification Marginal evidence (5)*	Loss Apparently as a result of acidification Adequate evidence ($\geq$ 6)
Brook trout	409	86	114**	98
Lake trout	68	25	10	8
Rainbow trout	54	34		2
Lake whitefish	28	24		1
Smallmouth bass	92	42		2
Largemouth bass	49	12		1
Chain pickerel	29	12		0
White sucker	336	66		10
Brown bullhead	420	74	13	13
Pumpkinseed sunfish	240	104		7
Yellow perch	185	80		2
Golden shiner	213	83	18	12
Creek chub	147	100		7
Lake chub	6	12		0

*Includes populations rated 5 for species with a rating of 5 associated with significantly lower lake pH. (refer to Figures 79 to 94).

**Includes 71 lakes considered 'typical brook trout habitat', with only recent survey data available and no fish caught.

13. WHAT IS THE RELATIONSHIP BETWEEN FISH POPULATION STATUS AND LAKE pH AND WATER COLOR?

For the seven species with ratings of population status covering sufficient range, the relationship between population status and lake pH, and the influence of water color, were evaluated using logistic regression analysis as described in Section 8. A binary dependent variable was defined:

STATUS = 1, if the confidence rating for population loss = 0, i.e., population still present in the lake

STATUS = 0, if the confidence rating for population loss > 0 (apparent loss of population) and the rating indicating likelihood that the population loss resulted from acidification ≥ 5 or ≥ 6, dependent on the species (refer to Table 8)

Results from these analyses are plotted in Figures 101 to 109, as the predicted probability (and 95% confidence limit) that status = 1 (i.e., population still present in lake) as a function of lake pH, and summarized in Table 9. The relationship between population status and lake pH was significant ($p \leq 0.05$) for all seven species. Water color had no significant ($p \geq 0.05$) effect on fish population status. These results should be interpreted with care, however, because of the small number of observations with status = 0 for some species.

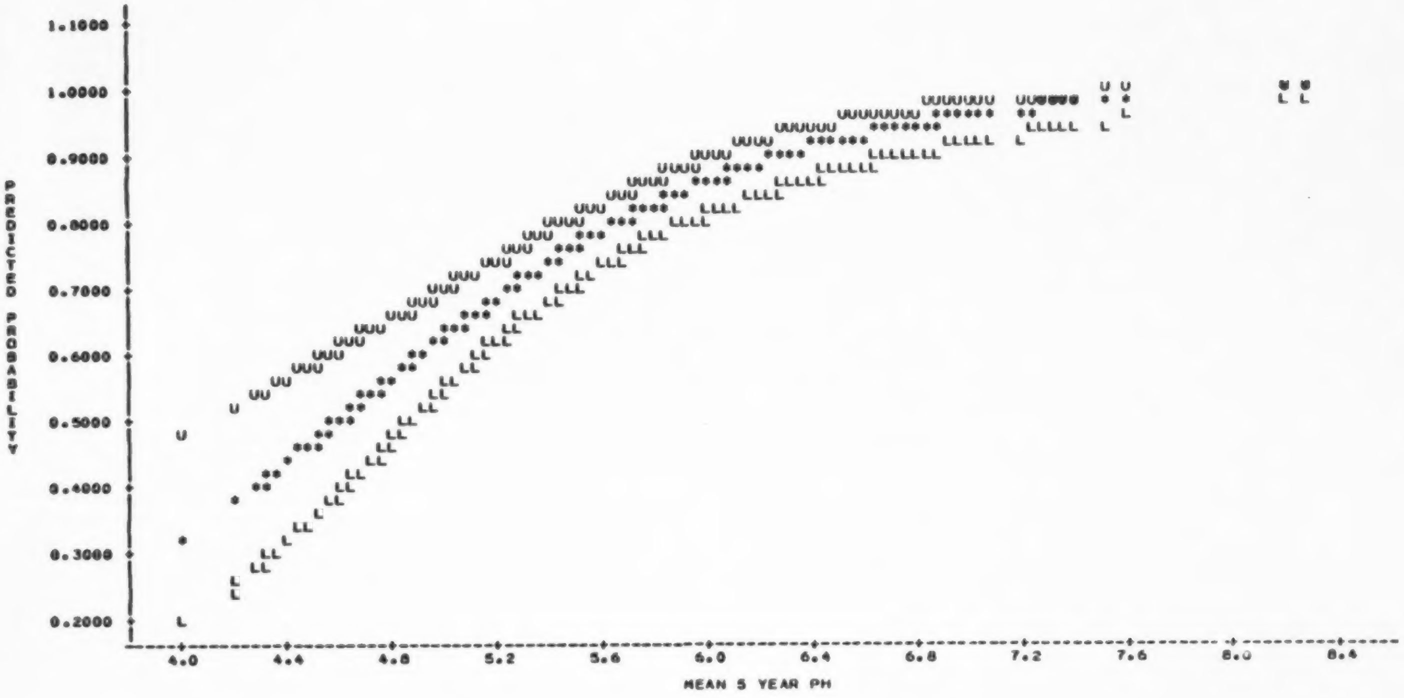

Figure 101. Predicted probability (and 95% confidence interval: U to L) that brook trout status = 1 (population present) as a function of mean 5-year pH.

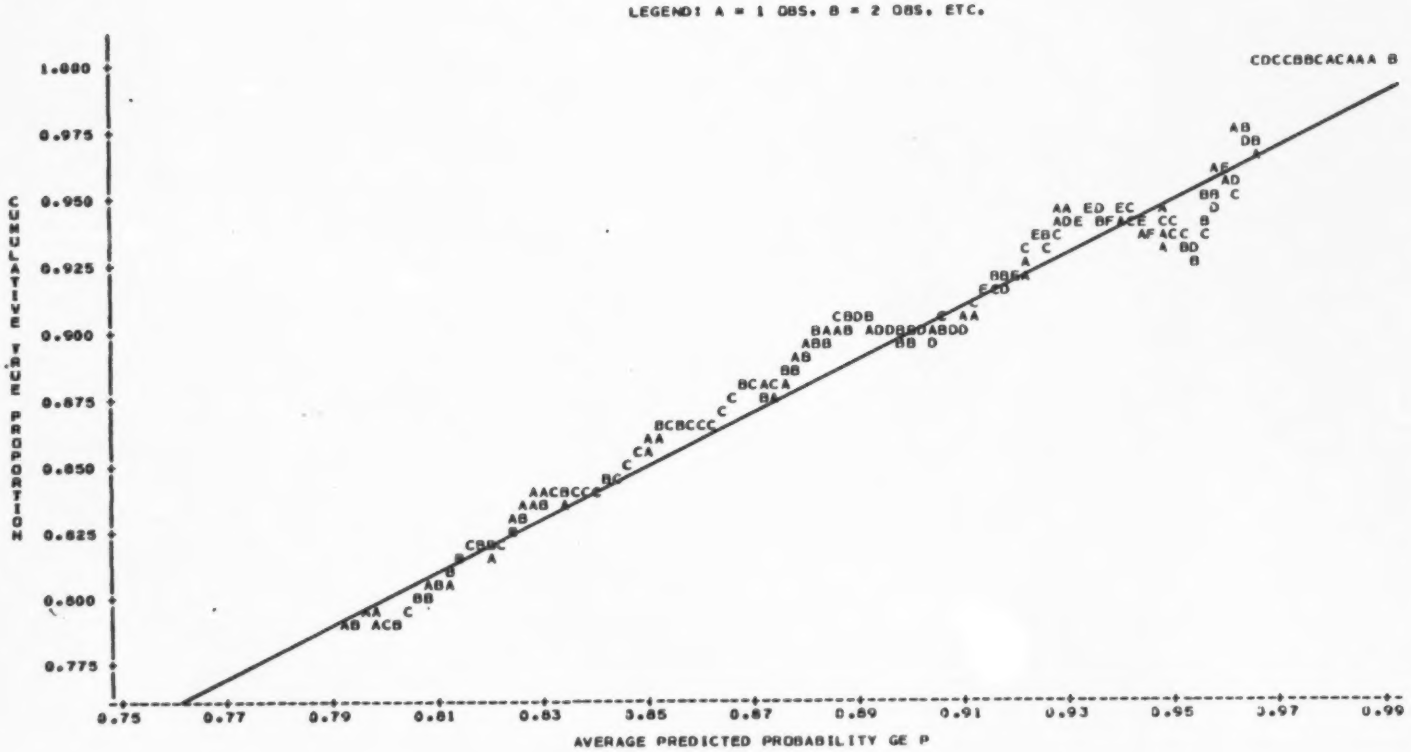

Figure 102. For a given probability, P , cumulative true proportion of brook trout populations with status = 1 (population present) for those populations having a predicted probability $\geq$ P, plotted as a function of the average predicted probability of those $\geq$ P. A 1:1 relationship is anticipated if the logistic model adequately represents the data.

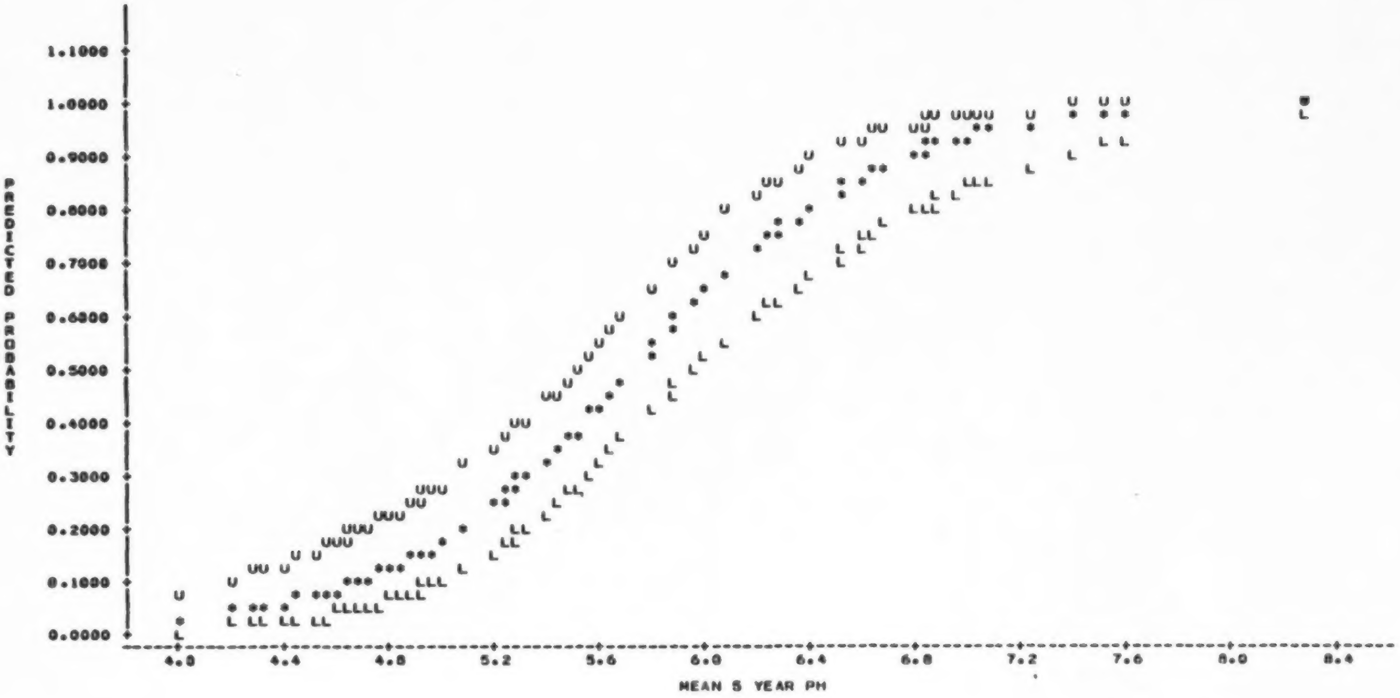

Figure 103. Predicted probability (and 95% confidence interval: U to L) that brook trout status = 1 (population present), as a function of mean 5-year pH, for naturally repreducing populations only.

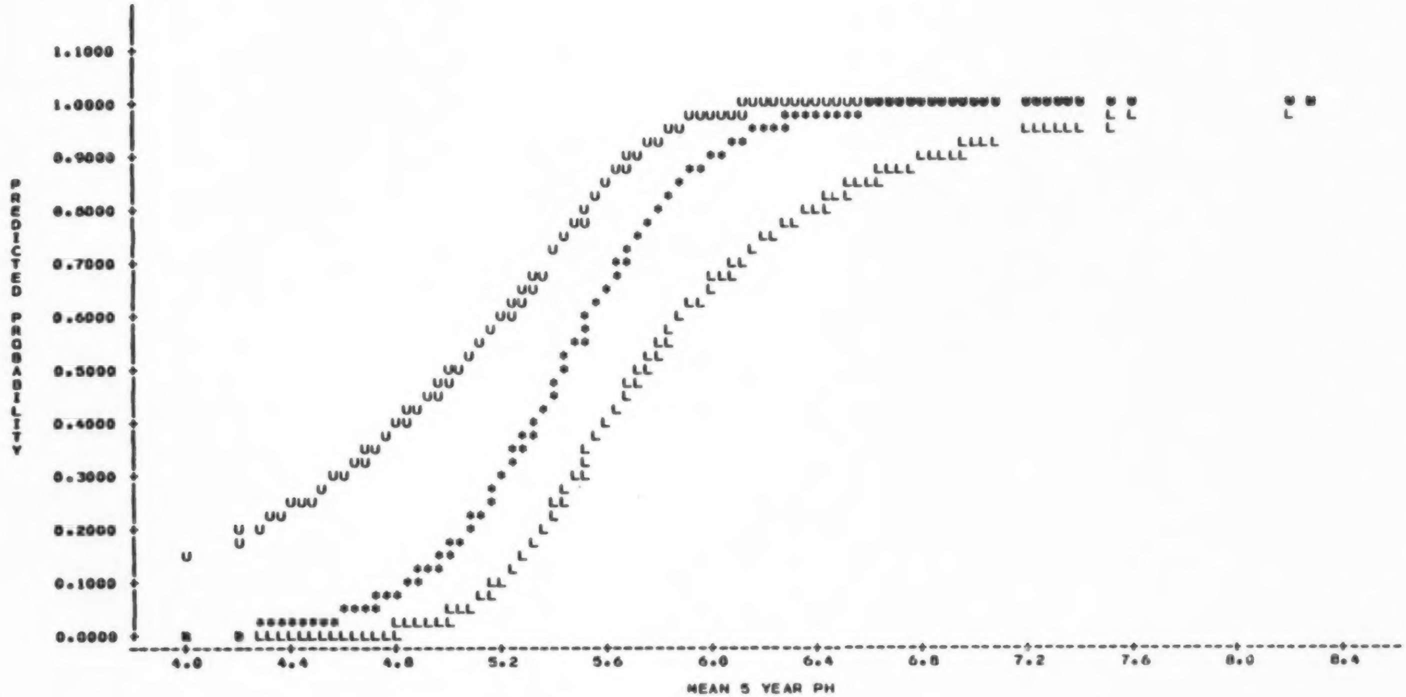

Figure 104. Predicted probability (and 95% confidence interval: U to L) that lake trout status = 1 (population present), as a function of mean 5-year pH.

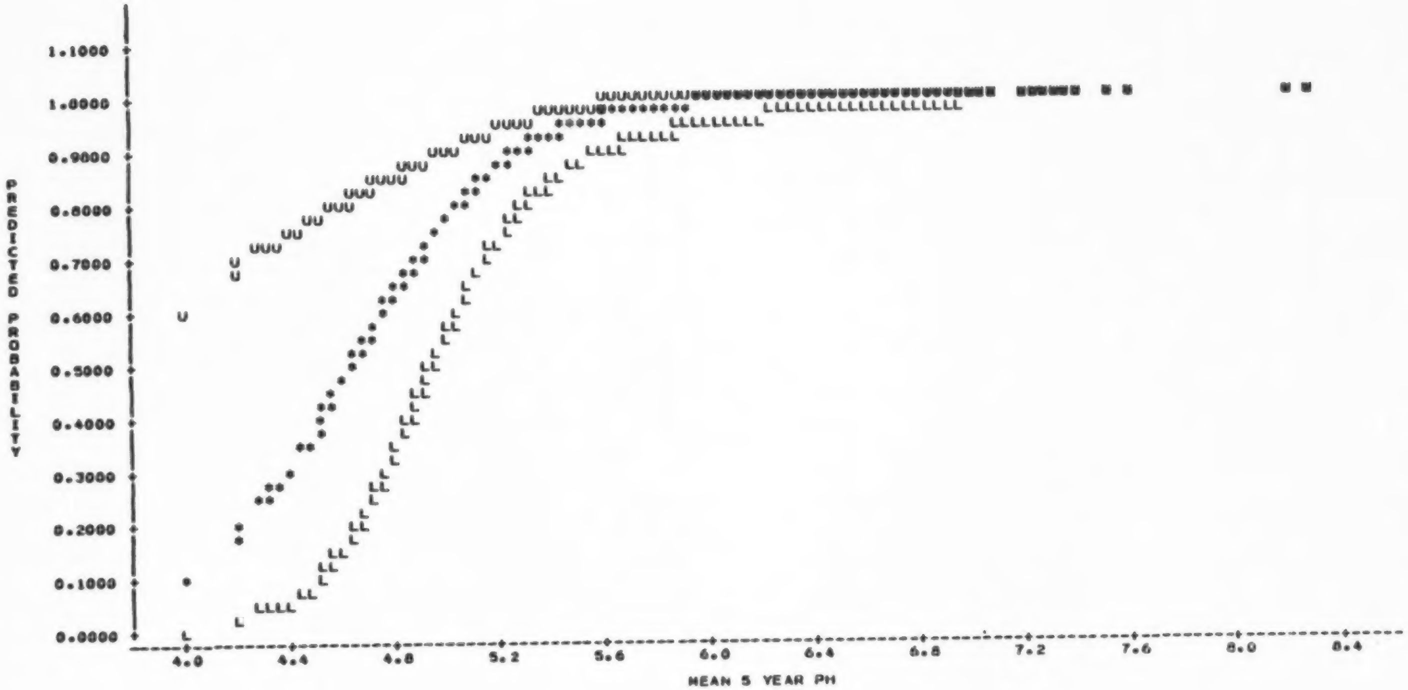

Figure 105. Predicted probability (and 95% confidence interval: U to L) that white sucker status = 1 (population present), as a function of mean 5-year pH.

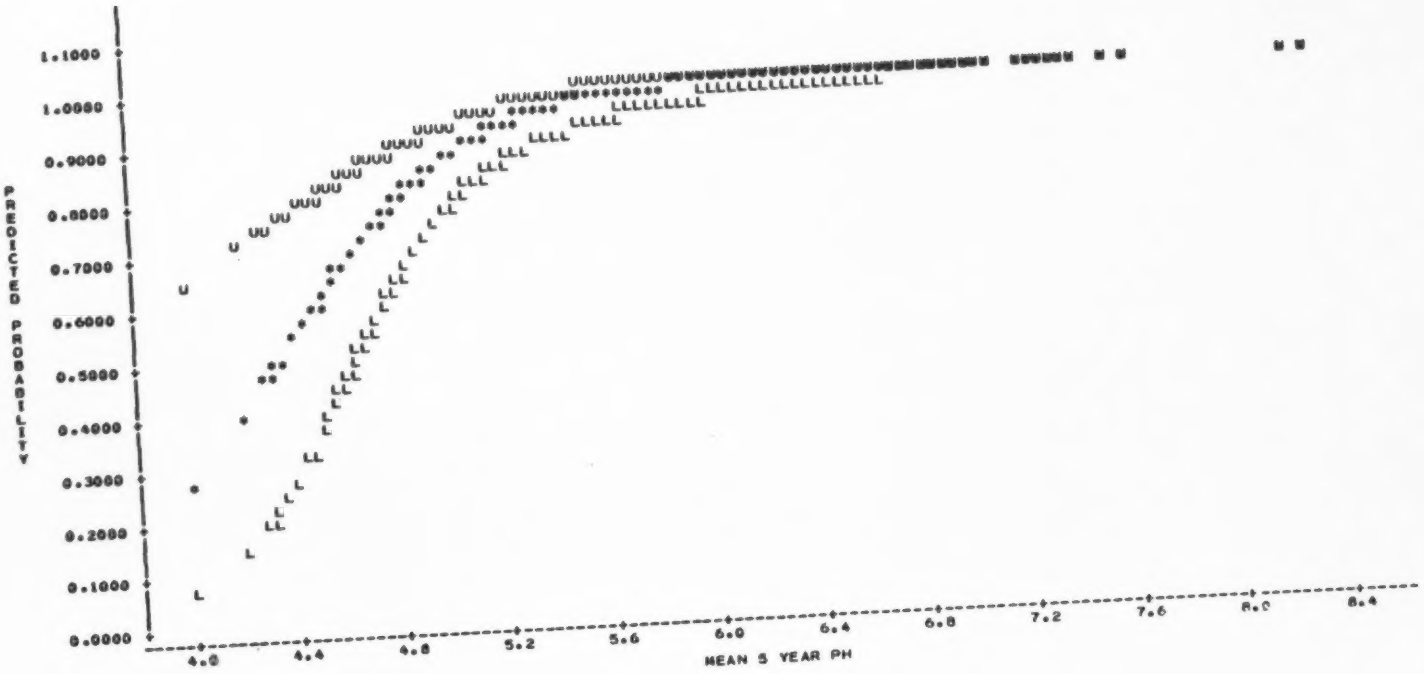

Figure 106. Predicted probability (and 95% confidence interval: U to L) that brown bullhead status = 1 (population present), as a function of mean 5-year pH.

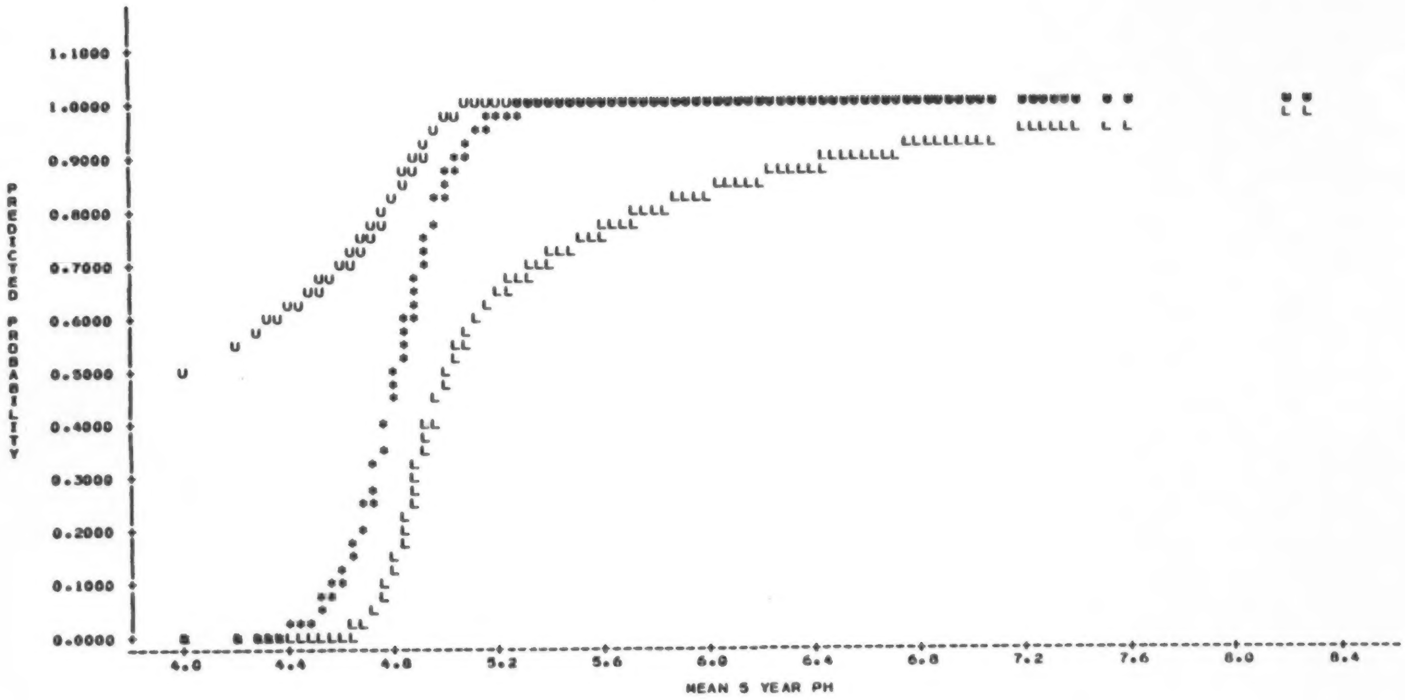

Figure 107. Predicted probability (and 95% confidence interval: U to L) that pumpkinseed sunfish status = 1 (population present), as a function of mean 5-year pH.

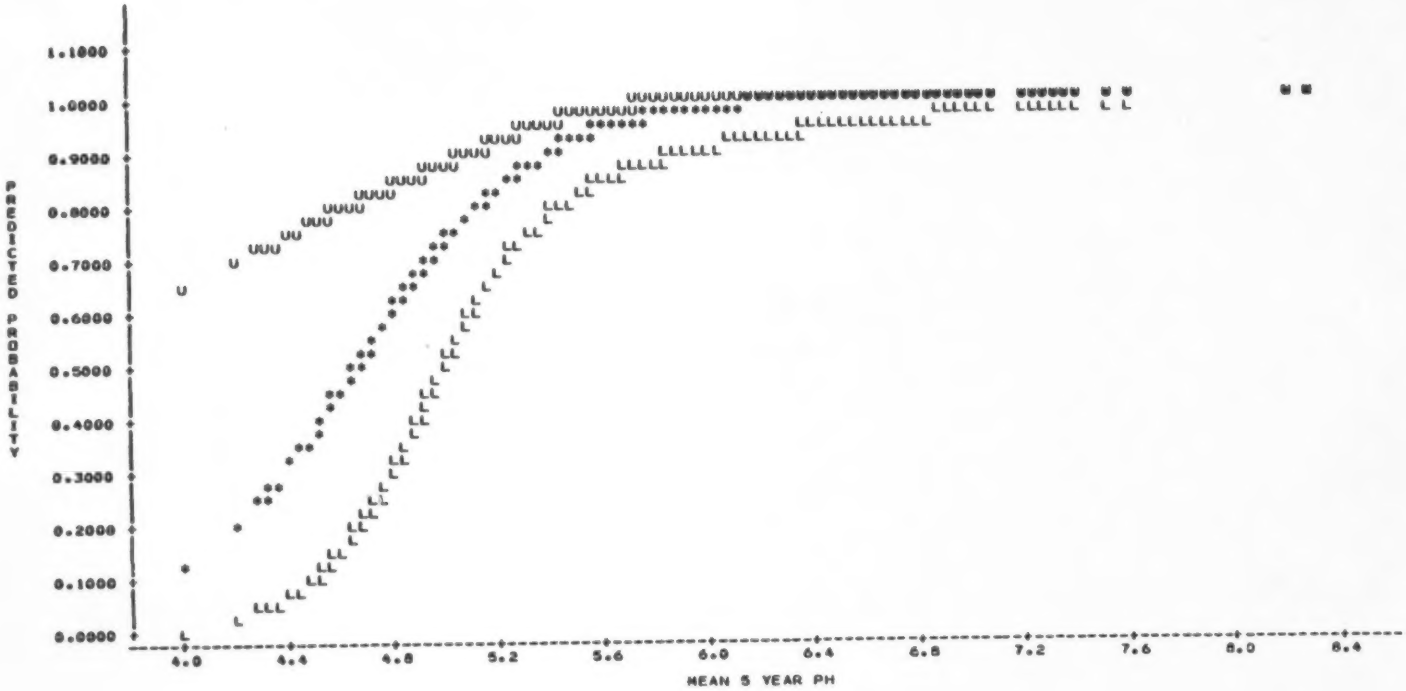

Figure 108. Predicted probability (and 95% confidence interval: U to L) that golden shiner status = 1 (population present), as a function of mean 5-year pH.

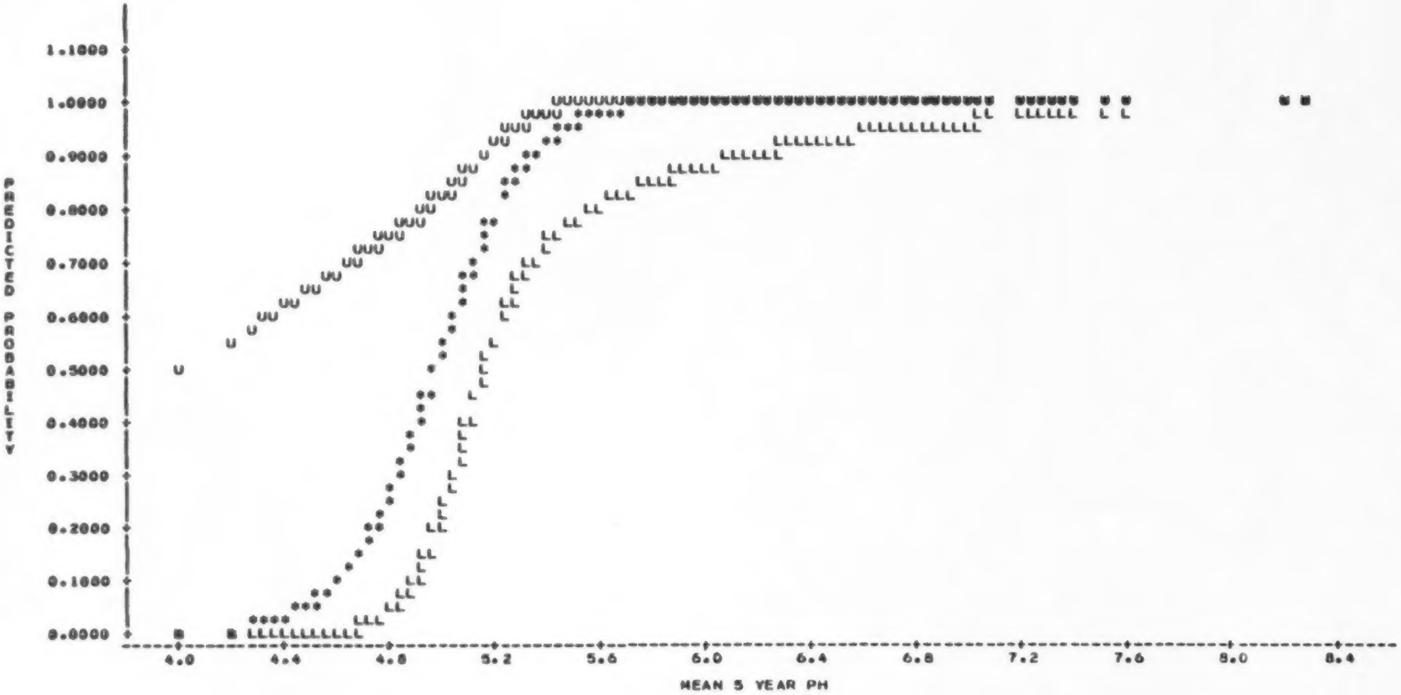

Figure 109. Predicted probability (and 95% confidence interval: U to L) that creek chub status = 1 (population present), as a function of mean 5-year pH.

Table 9. Summary of results: logistic regression of fish population status as a function of lake pH and water color.

Parameter	Brook Trout		Lake* Trout	White Sucker	Brown Bullhead	Pumpkinseed Sunfish	Golden Shiner	Creek Chub
	All Populations	Natural* Reproduction						
Model Coefficients:								
Intercept	-5.95	-12.06	-20.71	-15.69	-12.48	-45.30	-13.80	-29.42
pH	1.23	2.11	3.38	3.38	2.87	9.39	2.96	5.91
Std. Error:								
Intercept	1.16	1.92	6.52	5.32	3.58	21.13	5.26	12.64
pH	0.21	0.34	1.18	1.01	0.71	4.31	1.00	2.44
Chi-Square:								
Intercept	26.31	39.35	10.10	8.71	12.12	4.60	6.88	5.41
pH	37.51	38.61	10.50	11.24	16.14	4.74	8.79	5.88
P:pH	0.0000	0.0000	0.0012	0.0008	0.0001	0.0294	0.0030	0.0153
Regression coefficient	0.348	0.601	0.703	0.576	0.564	0.799	0.532	0.648
Rank correlation	0.507	0.777	0.864	0.913	0.863	0.0980	0.832	0.910
Number of Observations:								
Status = 1	290	63	39	212	270	140	130	102
Status = 0	76	71	10	7	11	4	7	5
Model Coefficients								
Intercept	-5.92	-12.15	-18.39	-15.26	-12.91	-46.64	-16.02	-40.36
pH	1.25	2.07	3.41	3.19	2.83	9.82	3.21	7.79
Water color	0.52	0.57	0.55	8.70	1.59	- 0.38	2.44	2.79
Std. Error:								
Water color	0.30	0.49	1.56		0.85	1.96	1.24	1.84
P:Water color	0.0871	0.2463	0.7223		0.0599	0.8468	0.0502	0.1291
Regression coefficient	0.353	0.597	0.635	0.627	0.0588	0.750	0.562	0.602
Rank Correlation	0.522	0.776	0.861	0.966	0.907	0.982	0.914	0.932
Number of Observations								
Status = 1	273	60	37	204	253	131	122	98
Status = 0	72	67	8	5	11	3	6	3

*Status = 0, defined as rating ≥ 5 for likelihood of loss as result of acidification. All other models based on ratings > 5.

V. SUMMARY

We have attempted to address a series of key questions regarding the acidity status of Adirondack lakes and potential effects of acidification on fish communities using existing water chemistry and fish survey data available within the FIN (Fish Information Network) data base (Baker et al. 1984). Each of our answers must however be qualified due to uncertainties associated with the existing data base, particularly sample bias and data quality. All (or at least many) of these necessary qualifiers were reviewed in the previous discussion of data analysis and results. The following is a brief summary of the major conclusions. These conclusions, however, should not be taken out of context, i.e., without reference to the more detailed discussion of data limitations and unquantifiable uncertainties in the previous section.

1. Are there major problems with data quality or quantity that may bias results?

    - 1979 electrometric pH readings by the New York State Department of Environmental Conservation were consistently 0.5 to 1.0 (mean 0.70 ± 0.09) pH units too low. These data were excluded from analyses.

    - Data on inorganic aluminum and calcium concentrations in Adirondack lakes are insufficient and thus were not considered in analyses related to fish population status.

    - Data on dissolved organic carbon levels (DOC) and/or water color are also insufficient. Visual observations of water color (clear, light brown, brown) were, however, used as a qualitative indicator of high concentrations of dissolved organics. Hunsaker et al. (1985) observed that these visual color observations were significantly correlated with lake DOC as measured during EPA's Eastern Lake Survey in 1984.

    - Because of variations in fish survey techniques, changes in fish populations over time could not be expressed quantitatively as catch per unit effort or probability of catch or no catch. Instead, ordinal indicators of fish community or fish population status (changes through time) were assigned reflecting the quantity of data available and the likelihood that any observed decline or loss of a fish population resulted from acidification (i.e., the absence of obvious alternative explanations). Evaluations of fish community and population status were made blindly, with no information on lake identify or water chemistry.

2. How many acid lakes are there in the Adirondacks?

    - Acid lakes were arbitrarily defined as having pH < 5.0.

    - 693 lakes have laboratory electrometric, air-equilibrated pH measurements within the last 10 years (1974-1983 excluding 1979).

Of these 693 lakes, 24.7% (171) had mean summer surface pH values below 5.0. Lakes with $pH < 5.0$ constituted 4.2% of the total lake surface area.

- Adjusting the sample for potential biases related to lake area and/or elevation, an estimated 17 to 28% (mean 22%) of the 2759 lakes in the Adirondack Ecological Zone are acidic ($pH < 5.0$) (1.4 - 6.8%; mean 4.1% on the basis of surface area).

- The sample of 693 lakes, however, may be biased in ways unassociated with area and elevation. We can neither identify nor correct for these biases, if they exist.

- Errors in the measurement of true lake pH may also bias the estimates of numbers of acidic lakes (in addition to increasing the variance associated with these estimates). Although we could not quantify the magnitude of this bias, it appeared relatively small, especially as compared to biases associated with sample selection.

3. Is there a significant positive correlation between acidity status and concentrations of dissolved organics?

- Relative concentrations of dissolved organics were expressed by a binary indicator based on visual observations of water color as clear (0) or light brown/brown (1).

- Current (1974-1983) pH levels in clear-water lakes were significantly ($p \leq 0.01$) lower than current pH levels in lakes classified as light brown or brown.

- The proportion of lakes classified as light brown or brown (indicative of high concentrations of dissolved organics) decreased significantly ($p \leq 0.01$) with decreasing pH.

- The data do not support the contention that the presence of organic acids is the major factor controlling lake acidity. A negative correlation between pH and organic content, however, is not sufficient proof that acidic deposition is a major factor controlling the acidity of Adirondack lakes.

4. What proportion of acidic lakes have high concentrations of dissolved organics?

- 305 lakes have both current pH data and visual color observations. Of the 82 lakes with $pH < 5.0$, 43% were classified as colored light brown or brown.

- Lakes with $pH < 5$ are more likely to be highly colored if they are very small (< 50 ha) and occur at lower elevations.

- Extrapolation from the sample of 82 lakes to all acidic Adirondack lakes is difficult. It appears, however, that a high percentage, perhaps 40-50%, of the Adirondack lakes with pH < 5.0 are highly colored, indicative of fairly high concentrations of dissolved organics.

5. Is there evidence that pH levels in Adirondack lakes have decreased over time?

   - Temporal trends were evaluated using linear regressions of pH as a function of time. 650 lakes had adequate data (≥ 2 pH measurements spanning ≥ 10 years) for estimation of the rate of change in pH (b_1)

   - The regional trend coefficient ($\bar{b}_1 = 0.01 \pm .02$ pH units per decade) was not significantly ($p > 0.05$) different from zero.

   - Restricting the analysis to high elevation (> 610 m) Adirondack lakes ($n = 130$), the regional trend coefficient ($\bar{b}_1 = -0.12 \pm .05$ pH units $n = 130$ per decade) was significantly ($p \leq 0.05$) less than zero, suggesting an overall decline in pH over time in high elevation lakes.

   - Restricting the analysis to lakes currently acidic (pH < 5.0), the regional trend coefficient ($\bar{b}_1 = -0.29 \pm .05$ pH units per decade) was also significantly ($p \leq 0.05$) less than zero. For the 81 acidic lakes with sufficient data for analysis of trends, pH levels declined ($b_1 < 0$) in 71 lakes (88%). Ten lakes (12%) experienced statistically significant ($p \leq 0.05$) decreases in pH over time; none experienced a statistically significant increase in pH over time.

6. Have changes in pH over time occurred independently of concentrations of organic acids?

   - Estimates of the rate of change in pH over time (pH units per decade) were not significantly ($p > 0.05$) different for clear-water lakes ($\bar{b}_1=0.00 \pm .05$) and lakes classified as light brown or brown ($\bar{b}_1=0.01 \pm .04$).

   - Limiting the analysis to high elevation lakes or currently acidic lakes yielded similar results.

   - Thus, there is no basis for presuming that acidic lakes with high concentrations of dissolved organics have always been acidic. We have not, however, distinguished causes for acidification.

7. Is there evidence that Adirondack fish communities have been adversely affected by acidification?

   - Ratings of fish community status were significantly ($p \leq 0.05$) correlated with lake pH. This correlation, while not proving cause-and-effect, adds credence to the argument that fisheries declines have occurred in the Adirondacks as a result of acidification.

- Ratings of fish community states were only weakly correlated ($p \leq 0.10$) with the estimated rate of change in pH over time. Rate of change in pH over time and current pH levels are highly correlated. Thus, ratings of fish community status were not correlated ($p > 0.05$) with rate of change in pH after adjustment for differences in current lake pH.

8. What is the functional relationship between fish community status and lake pH?

- Analyses of fish community status as a function of lake pH were based on the logistic regression model.
- The predicted probability that the fish community in a given lake is 'healthy' (no major change in species richness over time) increases ($p \leq 0.0001$) with increasing pH (Figure 50). The rank correlation between predicted probability and response = 0.810.

9. Does the presence of high concentrations of dissolved organics modify the relationship between fish community status and lake pH?

- Inclusion of the binary variable, water color, based on visual observations of water color, as an independent variable in the logistic regression model was significant at $p \leq 0.05$. The rank correlation between predicted probability and response = 0.843 for the model fish community status = f (lake pH and water color).
- At a given pH, the predicted probability that a fish community is 'healthy' is significantly ($p < 0.05$) higher in waters classified as light brown/brown than in clear-water lakes. This relationship suggests that either (1) fish communities can 'tolerate' lower pH levels in waters with higher concentrations of dissolved organics, or (2) fish species that tend to occur in light brown/brown-water lakes are more tolerant of acidic conditions than are fish species that occur in clear-water lakes.

10. How many fish communities have been adversely affected by acidification in the Adirondacks?

- 604 lakes had sufficient data for rating fish community status. 49 of these lakes (8.1%) received ratings of fish community status ≥ 3, indicative of the loss of some or all fish populations in the lake apparently as a result of acidification. 64 additional lakes (10.6%) received ratings of 2, indicating marginal evidence for adverse effects of acidification.
- Misclassification of the status of fish communities certainly occurred. Quantification of these error rates, however, would require comparison of our ratings of fish community status to

actual values for a sample of lakes of known status. No such data exist.

- The estimated number of fish communities adversely affected by acidification varies with the criteria for defining adequate evidence for detecting effects.

- Lakes with adequate data for rating fish community status tend to be larger and have higher pH than lakes in the Adirondacks in general. As a result, the percentage of lakes with fish communities adversely affected by acidification in our sample of 604 lakes probably underestimates the percentage of lakes affected in the Adirondacks as a whole. Correction for biases associated with lake pH may approximately double the predicted percentage of communities adversely affected, e.g., from 8.1% (with ratings $\geq$ 3) to 17.9% ($\pm$ 3.4%). Unfortunately, our understanding of the biases associated with our subset of 604 lakes is inadequate, and any extrapolations may be inaccurate.
- Lakes with only recent fish survey data were not included in estimates of numbers of fish communities adversely affected by acidification based on ratings of fish community status. Several groups of lakes deserve special attention. 30 lakes stocked with brook trout were surveyed and no fish caught. 88 lakes (not stocked) were surveyed and no fish were caught (or only brown bullhead). 31 lakes were surveyed and only brook trout (and in some lakes brown bullhead) were caught. Mean pH values for these 3 groups of lakes were 5.11, 5.16, and 5.70, respectively. Some or all of these fish communities have probably been adversely affected by acidification.

- Estimates of numbers of fish communities adversely affected (loss of one or more populations) by acidification vary from 50 to 200-250, depending upon the definition of 'adequate evidence' for detection of effects. For Adirondack lakes in general 400-500 (14-18%) may have been adversely affected. These are, however, fairly rough estimates and associated levels of uncertainty cannot be quantified.

- We have not distinguished causes for acidification.

11. Is there evidence that fish populations have been lost from Adirondack lakes as a result of acidification?

  - Changes in population status over time were evaluated for 14 fish species. Evaluation at the population level proved more difficult than evaluations of effects on fish communities.

  - Ratings of fish population status were significantly correlated ($p \leq 0.05$) with lake pH, supporting the argument that at least some populations have been lost from Adirondack lakes as a result of acidification.

- Ratings of fish population status were not significantly ($p > 0.05$) correlated with the estimated rate of pH change over time, after adjustment for differences due to lake pH.

12. How may fish populations have been lost from Adirondack lakes apparently as a result of acidification?

- Problems associated with sample bias and separating effects due to acidification at the population level prevent us from estimating the total number of fish populations lost from Adirondack lakes.

- For the 879 lakes surveyed at least once post-1960, numbers of populations classified as lost apparently as a result of acidification (Table 8) are:

brook trout	98-212
lake trout	8-18
rainbow trout	2
lake whitefish	1
smallmouth bass	2
largemouth bass	1
chain pickerel	0
white sucker	10
brown bullhead	13-26
pumpkinseed sunfish	7
yellow perch	2
golden shiner	12-30
creek chub	7
lake chub	0

- Our ability to detect fish population changes over time, and effects of acidification, is hampered by the quality of fish survey data available. The above numbers should be considered rough approximations.

13. What is the relationship between fish population status and lake pH and water color?

- Analyses of fish population status as a function of lake pH and water color were based on the logistic regression model.

- Data covering a sufficient range of pH and population status for estimation of model coefficients were available for 7 species.

- The predicted probability that a fish population in a given lake is 'healthy' increases ($p \leq 0.05$) as pH increases (Figures 101 to 109). Water color had no significant effect ($p>0.05$).

It is interesting to note that none of the above conclusions contradicts statements previously published by other investigators.

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VII. APPENDIX

Table A1. Recommended ratings for Phase I evaluation of fish population status, for lakes sampled in 5 or more years over a 20 or more year period. Recommended ratings listed in order as confidence that the population is: 'OK', declining, lost.

Species abundance	Species originally abundant Consistently caught				Species fairly common although not consistently caught in most nets				Species always rare; only caught sporadically			
Sampling effort and techniques	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns
1. C/E* constant or increasing; fish of all sizes caught	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0
2. C/E lower in most recent sample												
a. Slight decrease	8, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	8, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0
b. Significant decrease	6, 1, 0	7, 0, 0	7, 0, 0	7, 0, 0	6, 1, 0	7, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0	7, 0, 0
c. Only a few large fish left	5, 3, 0	6, 2, 0	6, 1, 0	7, 0, 0	5, 3, 0	5, 2, 0	6, 1, 0	6, 0, 0	6, 2, 0	7, 1, 0	7, 0, 0	7, 0, 0
3. Gradual decline in C/E with time	5, 2, 0	5, 1, 0	6, 1, 0	6, 0, 0	5, 2, 0	5, 1, 0	6, 1, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0
4. C/E lower in 2 most recent samples												
a. Slight decrease	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	7, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	6, 0, 0
b. Significant decrease	4, 2, 0	5, 2, 0	5, 1, 0	5, 0, 0	4, 2, 0	5, 2, 0	5, 1, 0	5, 0, 0	4, 1, 0	5, 1, 0	6, 0, 0	6, 0, 0
c. Small fish lacking in most recent sample	2, 5, 0	3, 4, 0	4, 4, 0	4, 2, 0	2, 4, 0	3, 4, 0	4, 3, 0	4, 2, 0	3, 3, 0	4, 3, 0	5, 2, 0	5, 1, 0
d. Small fish lacking in 2 most recent samples	1, 7, 0	2, 5, 0	3, 4, 0	3, 2, 0	1, 6, 0	2, 4, 0	3, 3, 0	3, 2, 0	2, 4, 0	3, 3, 0	4, 2, 0	4, 1, 0
5. C/E significantly lower in 3 or more most recent samples												
a. With no apparent recruitment failure	3, 4, 0	4, 3, 0	4, 1, 0	4, 0, 0	3, 4, 0	4, 3, 0	4, 1, 0	4, 0, 0	3, 2, 0	4, 1, 0	4, 0, 0	4, 0, 0
b. Small fish lacking; only a few, larger fish left	1, 8, 0	2, 7, 0	2, 5, 0	3, 3, 0	1, 7, 0	2, 6, 0	2, 5, 0	3, 3, 0	2, 6, 0	3, 5, 0	3, 3, 0	4, 1, 0
6. Species absent in most recent sample												
a. With no previous decrease in C/E	2, 5, 4	2, 4, 3	3, 3, 2	3, 2, 2	2, 5, 4	3, 4, 3	3, 2, 2	3, 1, 1	2, 3, 3	3, 3, 3	3, 2, 1	3, 0, 0
b. Some previous decline in C/E	2, 6, 5	2, 5, 4	2, 3, 3	3, 2, 1	2, 6, 5	2, 5, 4	2, 3, 3	3, 2, 1	2, 4, 3	3, 3, 2	3, 2, 1	3, 1, 0
c. Previous decline in C/E; small fish lacking	1, 7, 6	2, 6, 5	2, 5, 4	3, 3, 2	2, 7, 6	2, 6, 5	2, 5, 4	3, 3, 2	2, 5, 4	2, 4, 3	3, 3, 2	3, 2, 1
7. Species absent in 2 most recent samples												
a. With no previous decline in C/E	1, 8, 8	1, 6, 5	2, 5, 4	2, 4, 3	1, 8, 7	2, 6, 5	2, 5, 4	3, 4, 2	2, 5, 4	3, 4, 3	3, 3, 3	3, 2, 1
b. With previous decline in C/E	0, 9, 9	1, 7, 6	2, 6, 5	2, 5, 4	1, 9, 8	1, 7, 6	2, 6, 5	3, 5, 3	2, 6, 5	2, 5, 4	3, 4, 3	3, 3, 2
c. With previous decline in C/E; and small fish lacking	0, 9, 9	0, 7, 6	1, 7, 6	2, 5, 4	0, 9, 8	1, 7, 6	2, 6, 5	3, 5, 4	0, 6, 5	1, 6, 5	2, 5, 4	3, 4, 3
8. Species absent in 3 or more most recent samples												
a. With no previous decline in C/E	0, 9, 9	0, 8, 8	1, 6, 5	2, 5, 4	0, 9, 9	1, 8, 8	2, 6, 5	2, 5, 4	0, 7, 6	1, 6, 5	2, 5, 4	2, 2, 2
b. With previous decline in C/E	0, 9, 9	0, 9, 9	0, 7, 6	1, 5, 4	0, 9, 9	0. 9, 9	1, 7, 6	1, 5, 4	0, 7, 6	1, 6, 5	2, 5, 4	2, 4, 2
c. With previous decline in C/E and small fish lacking	0, 9, 9	0, 9, 9	0, 7, 6	1, 5, 4	0, 9, 9	0, 9, 9	1, 7, 6	1, 5, 4	0, 8, 7	1, 7, 6	1, 5, 4	2, 4, 2

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*Catch per unit of effort

Table A2. Recommended ratings for Phase I evaluation of fish population status, for lakes sampled in 4 years over a 10 or more year period. Recommended ratings listed in order as confidence that the population is 'OK', declining, lost.

Species abundance	Species originally abundant Consistently caught				Species fairly common although not consistantly caught in most nets				Species always rare; only caught sporadically			
Sampling effort and techniques	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns
1. C/E* constant or increasing; fish of all sizes caught	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0	9, 0, 0
2. C/E lower in most recent sample												
a. Slight decrease	7, 0, 0	7, 0, 0	8, 0, 0	8, 0, 0	7, 0, 0	7, 0, 0	8, 0, 0	8, 0, 0	7, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0
b. Significant decrease	6, 1, 0	6, 0, 0	7, 0, 0	7, 0, 0	6, 1, 0	6, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0	7, 0, 0
c. Only a few, large fish left	5, 3, 0	5, 2, 0	6, 1, 0	6, 0, 0	5, 3, 0	5, 2, 0	6, 1, 0	6, 0, 0	5, 2, 0	5, 1, 0	6, 0, 0	6, 0, 0
3. Gradual decline in C/E with time	5, 2, 0	5, 1, 0	6, 1, 0	6, 0, 0	5, 2, 0	5, 1, 0	6, 1, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0
4. C/E lower in 2 most recent samples												
a. Slight decrease	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	6, 0, 0
b. Significant decrease	4, 2, 0	4, 1,0	5, 1, 0	5, 0, 0	4, 2, 0	5, 1, 0	5, 1, 0	5, 0, 0	4, 1, 0	5, 1, 0	6, 0, 0	6, 0, 0
c. Small fish lacking in most recent sample	2, 5, 0	3, 4, 0	4, 4, 0	4, 2, 0	2, 4, 0	3, 4, 0	4, 3, 0	4, 2, 0	3, 3, 0	4, 3, 0	5, 2, 0	5, 1, 0
d. Small fish lacking in 2 most recent samples	1, 6, 0	2, 5, 0	3, 4, 0	3, 2, 0	1, 5, 0	2, 4, 0	3, 3, 0	3, 2, 0	2, 3, 0	3, 2, 0	4, 1, 0	4, 1, 0
5. C/E significantly lower in 3 most recent samples												
a. With no apparent recruitment failure	3, 4, 0	4, 3, 0	4, 1, 0	4, 0, 0	3, 3, 0	4, 2, 0	4, 1, 0	4, 0, 0	3, 2, 0	4, 1, 0	4, 0, 0	4, 0, 0
b. Small fish lacking; only a few, larger fish left	1, 7, 0	2, 6, 0	2, 4, 0	3, 2, 0	1, 6, 0	2, 5, 0	2, 4, 0	3, 2, 0	2, 4, 0	3, 3, 0	3, 2, 0	4, 1, 0
6. Species absent in most recent samples												
a. With no previous decline in C/E	2, 5, 4	2, 4, 3	3, 3, 2	3, 2, 2	2, 5, 4	3, 4, 3	3, 2, 2	3, 1, 1	2, 3, 3	3, 3, 3	3, 2, 1	3, 0, 0
b. Some previous decline in C/E	2, 6, 5	2, 5, 4	2, 3, 3	3, 2, 1	2, 6, 5	2, 5, 4	2, 3, 3	3, 2, 1	2, 4, 3	3, 3, 2	3, 2, 1	3, 1, 0
c. Previous decline in C/E and small fish lacking	1, 7, 6	2, 6, 5	2, 5, 4	3, 3, 2	2, 7, 6	2, 6, 5	2, 5, 4	3, 3, 2	2, 5, 4	2, 4, 3	3, 3, 2	3, 2, 1
7. Species absent in 2 most recent samples												
a. With no previous decline in C/E	1, 8, 8	1, 6, 5	2, 5, 4	2, 4, 3	1, 8, 7	2, 6, 5	2, 5, 4	3, 4, 2	2, 5, 4	3, 4, 3	3, 3, 2	3, 2, 1
b. With previous decline in C/E	0, 8, 8	1, 6, 5	2, 5, 4	2, 4, 3	1, 8, 8	1, 6, 5	2, 5, 4	3, 4, 3	2, 5, 4	2, 4, 3	3, 3, 2	3, 2, 1
c. With previous decline in C/E and small fish lacking	0, 9, 9	0, 7, 6	1, 7, 6	2, 5, 4	0, 9, 8	1, 7, 6	2, 6, 5	3, 5, 4	0, 6, 5	1, 6, 5	2, 5, 4	3, 4, 3
8. Species absent in 3 most recent surveys	0, 9, 9	0, 8, 8	1, 7, 6	2, 5, 4	0, 9, 9	1, 8, 8	2, 6, 5	2, 5, 4	0, 7, 6	1, 6, 5	2, 5, 4	2, 2, 2

*Catch per unit of effort

Table A3. Recommended ratings for Phase I evaluation of fish population status, for lakes sampled in 3 years over a 10 or more year period. Recommended ratings listed in order as confidence that the population is: 'OK', declining, lost.

Species abundance	Species originally abundant Consistently caught				Species fairly common although not consistantly caught in most nets				Species always rare; only caught sporadically			
Sampling effort and techniques	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns
1. C/E* constant or increasing; fish of all sizes caught	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0	8, 0, 0
2. C/E lower in most recent sample												
a. Slight decrease	6, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0	7, 0, 0
b. Significant decrease	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	7, 0, 0
c. Only few larger fish left	4, 3, 0	4, 2, 0	5, 1, 0	5, 0, 0	4, 3, 0	4, 2, 0	5, 1, 0	5, 0, 0	4, 2, 0	4, 1, 0	5, 0, 0	5, 0, 0
3. Gradual decline in C/E with time	5, 2, 0	5, 1, 0	6, 1, 0	6, 0, 0	5, 2, 0	5, 1, 0	6, 1, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0
4. C/E lower in 2 most recent samples												
a. Slight decrease	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 1, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	6, 0, 0
b. Significant decrease	4, 2, 0	4, 1, 0	5, 1, 0	5, 0, 0	4, 2, 0	4, 1, 0	5, 0, 0	5, 0, 0	4, 1, 0	5, 1, 0	6, 0, 0	6, 0, 0
c. Small fish lacking in most recent sample	2, 4, 0	3, 3, 0	4, 2, 0	4, 1, 0	2, 3, 0	3, 2, 0	4, 1, 0	4, 1, 0	3, 2, 0	4, 2, 0	5, 1, 0	5, 0, 0
d. Small fish lacking in 2 most recent samples	1, 4, 0	2, 3, 0	3, 2, 0	3, 1, 0	1, 3, 0	2, 2, 0	3, 1, 0	3, 1, 0	2, 2, 0	3, 2, 0	4, 1, 0	4, 0, 0
5. Species absent in most recent sample												
a. With no previous decline in C/E	2, 5, 4	2, 4, 3	3, 3, 2	3, 2, 2	2, 5, 4	3, 4, 3	3, 2, 2	3, 1, 1	2, 3, 3	3, 3, 3	3, 2, 1	3, 0, 0
b. Some previous decline in C/E	2, 6, 5	2, 3, 3	3, 2, 2	3, 1, 1	2, 5, 4	2, 4, 3	3, 3, 3	3, 1, 1	2, 3, 3	3, 2, 2	3, 1, 1	3, 0, 0
c. Previous decline in C/E and small fish lacking	1, 6, 5	2, 5, 4	2, 3, 2	3, 2, 1	1, 6, 5	2, 5, 4	2, 3, 2	3, 2, 1	2, 4, 3	2, 3, 2	3, 2, 1	3, 1, 1
6. Species absent in 2 most recent samples	0, 8, 8	1, 6, 5	2, 5, 4	2, 4, 3	1, 8, 7	2, 6, 5	2, 5, 4	3, 4, 2	2, 5, 4	3, 4, 3	3, 3, 2	3, 2, 1

*Catch per unit of effort

Table A4. Recommended ratings for Phase I evaluation of fish population status, for lakes sampled in 2 years over a 10 or more year period. Recommended ratings listed in order as confidence that the population is: 'OK', declining, lost.

Species abundance	Species originally abundant Consistently caught				Species fairly common although not consistently caught in most nets				Species always rare only caught sporadically			
Sampling effort and techniques	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns
1. C/E equal or greater in second sample fish of all sizes caught	7, 0, 0	7, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	6, 0, 0	7, 0, 0	7, 0, 0
2. C/E lower in second sample												
a. Slight decrease	5, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0	6, 0, 0
b. Significant decrease	4, 2, 0	5, 0, 0	5, 0, 0	5, 0, 0	4, 1, 0	5, 0, 0	5, 0, 0	5, 0, 0	4, 0, 0	5, 0, 0	5, 0, 0	5, 0, 0
c. Only few, larger fish left	3, 2, 0	3, 2, 0	4, 1, 0	4, 0, 0	3, 2, 0	3, 2, 0	4, 2, 0	4, 0, 0	4, 1, 0	5, 1, 0	5, 0, 0	5, 0, 0
3. Species absent in second sample												
a. Fish of all sizes caught in first sample	1, 5, 4	2, 4, 3	3, 3, 2	3, 2, 2	2, 4, 3	2, 3, 3	2, 2, 2	2, 1, 1	2, 2, 2	3, 1, 1	4, 1, 1	5, 0, 0
b. Only larger (older) fish caught in first survey	1, 5, 4	2, 3, 3	2, 2, 2	3, 1, 1	1, 5, 4	2, 3, 3	2, 2, 2	2, 1, 1	1, 3, 2	2, 2, 1	2, 1, 1	2, 0, 0
4. Species absent in both samples												
a. Species stocked consistently, including years preceeding sample	1, 4, 3	1, 3, 2	1, 2, 1	1, 1, 0								
b. Species stocked sporadically	1, 2, 2	1, 1, 1	1, 0, 0	1, 0, 0								

Table A5. Recommended ratings for Phase I evaluation of fish population status, for lakes sampled only once. Recommended ratings listed in order as confidence that the population is: 'OK', declining, lost.

Species abundance	Species originally abundant Consistently caught				Species fairly common although not consistently caught in most nets				Species always rare only caught sporadically			
Sampling effort and techniques	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns	Adequate	Minor Concerns	Some Concerns	Serious Concerns
1. Species caught Fish of all sizes caught	7, 0, 0	7, 0, 0	7, 0, 0	7, 0, 0	6, 0, 0	6, 0, 0	6, 0, 0	6, 0, 0	5, 0, 0	5, 0, 0	6, 0, 0	6, 0, 0
2. Species caught, although only few large fish	3, 2, 0	4, 2, 0	4, 1, 0	4, 0, 0	4, 1, 0	4, 1, 0	4, 1, 0	5, 0, 0	3, 1, 0	3, 1, 0	4, 1, 0	4, 0, 0
3. Species absent												
a. Species stocked consistently, and reported to have occurred earlier	1, 5, 4	1, 4, 3	1, 1, 0	2, 0, 0								
b. Species stocked consistently, no other information	1, 4, 3	1, 2, 1	1, 1, 0	1, 0, 0								
c. Species stocked sporadically	1, 2, 2	1, 1, 1	1, 0, 0	1, 0, 0								
d. No stocking, but reported to have occurred earlier	1, 2, 2	1, 1, 1	1, 0, 0	1, 0, 0								
e. No stocking, but likely habitat	1, 1, 1	1, 1, 0	1, 0, 0	1, 0, 0								

Table A6. Numbers of brook trout populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	379	2						381
1	2	33	87			1		123
2-3		21	9	4	4			38
4-5	2	23	21	37	29	13	1	126
>5	2	20	6		4	6	1	39
TOTAL	385	99	123	41	37	20	2	707
Population Loss								
0	381	17	9		1	1		409
1		23	80					103
2-3		24	16	39	6			85
4-5	2	20	13	2	26	15	2	80
>5	2	15	5		4	4		30
TOTAL	385	99	123	41	37	20	2	707

Table A7. Numbers of naturally-reproducing brook trout populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	78	1						79
1		22	81					103
2-3		7	1					8
4-5		3	4		2			9
>5	1	3	1					5
TOTAL	79	36	87		2			204
Population Loss								
0	78	2	1					81
1		21	80					101
2-3		8	2					10
4-5		4	4		2			10
>5	1	1						2
TOTAL	79	36	87		2			204

Table A8. Numbers of lake trout populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	62							62
1		5						5
2-3	2	5	3			1		11
4-5	2	4	3	1	3			13
>5	8	5	4		2	1		20
TOTAL	74	19	10	1	5	2		111
Population Loss								
0	63	5						68
1		2						2
2-3	2	5	4	1		1		13
4-5	3	4	3		3			13
>5	6	3	3		2	1		15
TOTAL	74	19	10	1	5	2		111

Table A9. Numbers of natural reproducing lake trout populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification						
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	33							33
1		2						2
2-3	2	2	1			1		6
4-5	2	1	1		2			6
>5	5	1	3					9
TOTAL	42	6	5		2	1		56
Population Loss								
0	34	2						36
1		1						1
2-3	2	1	1			1		5
4-5	2	1	2		2			7
>5	4	1	2					7
TOTAL	42	6	5		2	1		56

Table A10. Numbers of rainbow trout populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	54							54
1								-
2-3	1	1	1					3
4-5	1	7	5	1	1			15
>5	2	15	1					18
TOTAL	58	23	7	1	1			90
Population Loss								
0	54							54
1								-
2-3	1	5	5	1				12
4-5	2	5	1		1			9
>5	1	13	1					15
TOTAL	58	23	7	1	1			90

Table A11. Numbers of lake whitefish populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	27							27
1		1						1
2-3		6	1					7
4-5		3	6					9
>5	5		3		1			9
TOTAL	32	10	10		1			53
Population Loss								
0	27	1						28
1		2						2
2-3		7	3					10
4-5	1		6					7
>5	4		1		1			6
TOTAL	32	10	10		1			53

Table A12. Numbers of smallmouth bass populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	88							88
1	1	4	2					7
2-3		8	4					12
4-5	4	5	6	1	1			17
>5	6	2	4					12
TOTAL	99	19	16	1	1			136
Population Loss								
0	88	3	1					92
1	1	4	1					6
2-3	3	6	7	1	1			18
4-5	2	4	4					10
>5	5	2	3					10
TOTAL	99	19	16	1	1			136

Table A13. Numbers of largemouth bass populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	49							49
1		1						1
2-3		3	2					5
4-5			2	1				3
>5	1	2	1					4
TOTAL	50	6	5	1				62
Population Loss								
0	49							49
1		2						2
2-3		2	3	1				6
4-5			1					1
>5	1	2	1					4
TOTAL	50	6	5	1				62

Table A14. Numbers of chain pickerel populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	29							29
1		4	1					5
2-3		3						3
4-5	2							2
>5	1	1						2
TOTAL	32	8	1					41
Population Loss								
0	29							29
1		5	1					6
2-3		2						2
4-5	3							3
>5		1						1
TOTAL	32	8	1					41

Table A15. Numbers of white sucker populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	320							320
1	3	5	1					9
2-3	5	10	2		1			18
4-5	11	3	5		6			25
>5	31	3	2		3	1		40
TOTAL	370	21	10		10	1		412
Population Loss								
0	326	6	3		1			336
1		2						2
2-3	4	7	3		1			15
4-5	11	4	3		6			24
>5	29	2	1		2	1		35
TOTAL	370	21	10		10	1		412

Table A16. Numbers of brown bullhead populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	410							410
1	3	7	1					11
2-3	4	8						12
4-5	14	16	9		5	2	1	47
>5	28	4	3		1	2	2	40
TOTAL	459	35	13		6	4	3	520
Population Loss								
0	415	4	1					420
1		3						3
2-3	6	8	4		2			20
4-5	11	16	7		3	2	1	40
>5	27	4	1		1	2	2	37
TOTAL	459	35	13		6	4	3	520

Table A17. Numbers of pumpkinseed sunfish populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	235							235
1		2	1					3
2-3	5	10	6		1			22
4-5	17	13	12		3		1	46
>5	36	2	5		1	1		45
TOTAL	293	27	24		5	1	1	351
Population Loss								
0	236	4						240
1			3					3
2-3	11	11	8		2			32
4-5	13	11	11		2		1	38
>5	33	1	2		1	1		38
TOTAL	293	27	24		5	1	1	351

Table A18. Numbers of yellow perch populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	181							181
1	1	5			2			6
2-3	3	7	1					13
4-5	16	6	5					27
>5	35	2	2				1	40
TOTAL	236	20	8		2		1	267
Population Loss								
0	181	3			1			185
1	1	2	1					4
2-3	7	8	2		1			18
4-5	14	6	3					23
>5	33	1	2				1	37
TOTAL	236	20	8		2		1	267

Table A19. Numbers of golden shiner populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	209							209
1	3	4						7
2-3	3	24	3		3			33
4-5	9	19	12		5	1		46
>5	13	11	3		2		2	31
TOTAL	237	58	18		10	1	2	326
Population Loss								
0	210	2			1			213
1	2	4						6
2-3	5	30	6		2			43
4-5	8	16	9		5	1		39
>5	12	6	3		2		2	25
TOTAL	237	58	18		10	1	2	326

Table A20. Numbers of creek chub populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	145							145
1		6	1					7
2-3	7	37	13		1			58
4-5	8	6	9		2	1		26
>5	7	4	4		2		1	18
TOTAL	167	53	27		5	1	1	254
Population Loss								
0	146	1						147
1		11	2					13
2-3	7	33	15		2			57
4-5	7	8	6		1	1	1	24
>5	7		4		2			13
TOTAL	167	53	27		5	1	1	254

Table A21. Numbers of lake chub populations with confidence ratings for population decline and population loss, sorted by ratings for likelihood that the observed loss/decline resulted from acidification.

Confidence Rating	Likelihood that the observed decline/loss resulted from acidification							
Population Decline	0	1-4	5	6	7	8	9	TOTAL
0	6							6
1								-
2-3		6						6
4-5		2	2					4
>5		1	1					2
TOTAL	6	9	3					18
Population Loss								
0	6							6
1								-
2-3		6	2					8
4-5		3						3
>5			1					1
TOTAL	6	9	3					18